# 临街建筑群间交通噪声一维分布灰色系统模型预测

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**摘要** 研究交通噪声在建筑群间传播与分布的计算机模拟方法,建立在物理模型的基础上. 由于噪声实际传播过程中未知因素太多,使由物理模型得出的预测结果在离声源较远处与实际相比有较大误差. 本文提出的灰色系统模型预测方法,首先给出非本征灰色系统中物理参量按坐标分布的一般 GM(1,1) 模型,用计算机模拟方法在其有效的范围内获取的数据构成原始序列,按 GM(1,1) 建模方法给出交通噪声按坐标分布的预测值,预测结果在离交通干道较远处的分布更符合实际情况,在此范围内提高了预测精度.

**关键词** 建筑群,交通噪声,灰色系统,预测模型.

交通噪声在临街建筑群中的传播与衰减是一个引人注目的课题. 通常用理论声学的方法对声场的分布进行计算[1]; 实验室缩尺模型的方法进行物理模拟;[2,3] 计算机产生道路随机车辆流模型的方法进行预测[4] 等等. 这些方法都是把产生交通噪声的声源及其周围环境当作一个白色系统来处理, 完全依赖于一定的物理模型. 事实上, 声波在建筑群间的传播是一个物理问题,但由于整个系统未知因素太多,使运用以上方法研究到一定程度后便无法进一步深入下去. 换言之, 交通噪声源与其周围环境构成一个非本征灰色系统,必须改变研究思路,用灰色系统的理论与方法, 以使问题的研究进一步深入.

## 1 物理参量按坐标分布的 GM(1,1) 模型

灰色系统理论中的预测模型 GM(1,1) 通常是对时间序列进行预测[5], 本文提出的按坐标分布的 GM(1,1) 模型建立如下:

设变量 $y^{(0)}$ 是按坐标 $x$ 一维分布的物理量,把 $y^{(0)}$ 写成序列形式:

$$y^{(0)} = \{y^{(0)}(1), y^{(0)}(2), \cdots, y^{(0)}(n)\}$$

其相应的微分模型为

$$\frac{dy^{(1)}}{dx} + ay^{(1)} = u \qquad (1)$$

其中,

$$\frac{dy^{(1)}}{dx} = \lim_{\Delta x \to 0} \frac{y^{(1)}(x + \Delta x) - y^{(1)}(x)}{\Delta x},$$

令 $\Delta x$ 足够密化并取 1 单位,把 $y^{(1)}$ 记为离散形式,有

$$\frac{dy^{(1)}}{dx} = y^{(1)}(k+1) - y^{(1)}(k) = y^{(0)}(k+1)$$

上式后一等号即为对 $y^{(1)}$ 作一次累减生成,其结果为 $y^{(0)}$;反之,$y^{(0)}$ 的一次累加生成即为 $y^{(1)}$. 这正是用 $y^{(1)}$ 而不用 $y^{(0)}$ 来建立微分模型的依据.

作为一级近似, 令 (1) 式中的 $a$、$u$ 是与 $x$ 无关的常量, 则(1)式可看成是 $dy^{(1)}/dy$ 与背景值 $\mathscr{Y}^{(1)}$ 的线性组合,有

$$y^{(0)}(k+1) + a\mathscr{Y}^{(1)}(k+1) = u \qquad (2)$$

合理地取 $y^{(1)}$ 在 $\Delta x$ 过程的中间值作为背景值,即

$$\mathscr{Y}^{(1)}(k+1) = \frac{1}{2}[y^{(1)}(k) + y^{(1)}(k+1)]$$

代入(2)式,有

$$y^{(0)}(k+1) = a\left[-\frac{1}{2}(y^{(1)}(k) + y^{(1)}(k+1)\right] + u \quad (k = 1,2,\cdots,n-1) \qquad (3)$$

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$$\boldsymbol{y}_N = \begin{pmatrix} y^{(0)}(2) \\ y^{(0)}(3) \\ \vdots \\ y^{(0)}(n) \end{pmatrix};$$

$$\mathscr{Y} = \begin{pmatrix} -\frac{1}{2}(y^{(1)}(1) + y^{(1)}(2)) \\ -\frac{1}{2}(y^{(1)}(2) + y^{(1)}(3)) \\ \vdots \\ -\frac{1}{2}(y^{(1)}(n-1) + y^{(1)}(n)) \end{pmatrix};$$

$$\boldsymbol{E} = \begin{pmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix}$$

则(3)式可表示为

$$\boldsymbol{y}_N = a\mathscr{Y} + u\boldsymbol{E} = \boldsymbol{B}\hat{\boldsymbol{a}} \qquad (4)$$

其中，

$$\boldsymbol{B} = (\mathscr{Y} \vdots \boldsymbol{E}) = \begin{pmatrix} -\frac{1}{2}(y^{(1)}(1) + y^{(1)}(2)) & 1 \\ -\frac{1}{2}(y^{(1)}(2) + y^{(1)}(3)) & 1 \\ \cdots\cdots & \\ -\frac{1}{2}(y^{(1)}(n-1) + y^{(1)}(n)) & 1 \end{pmatrix};$$

$$\hat{\boldsymbol{a}} = \begin{pmatrix} a \\ u \end{pmatrix}$$

于是可得

$$\hat{\boldsymbol{a}} = (\boldsymbol{B}^T\boldsymbol{B})^{-1}\boldsymbol{B}^T\boldsymbol{y}_N \qquad (5)$$

由(5)式求出 $\hat{\boldsymbol{a}}$ 后代入(1)式，便建立了关于 $y^{(1)}$ 的一阶微分方程模型，此即按坐标一维分布 GM(1,1) 建模过程.

方程(1)的通解为:

$$y^{(1)}(x) = e^{-ax}\left(\frac{u}{a}e^{ax} + C\right) \qquad (6)$$

为确定积分常数 $C$，将 $y^{(1)}$ 的初始值代入. 本模型 $x$、$y$ 均已离散化，故令 $x = 1$ 时，$y^{(1)}(1) = y^{(0)}(1)$ 作为初始条件，得

$$C = \left(y^{(0)}(1) - \frac{u}{a}\right)e^{a}$$

代回(6)式，并用离散化的序号 $k$ 来代替 $x$，即得模型解

$$\hat{y}^{(1)}(k+1) = \frac{u}{a} + \left(y^{(0)}(1) - \frac{u}{a}\right)e^{-ak} \qquad (7)$$

(7)式即可用来计算 $y^{(1)}$ 序列的预测值. 将预测值作累减生成，即得 $y^{(0)}$ 序列在 $x$ 轴上各离散点上的预测值.

## 2　交通噪声一维分布 GM(1,1) 预测方法

参见图 1，MN 为交通干道，$ox$ 为临街建筑间小巷，干道上交通噪声沿 $ox$ 传播，在小巷纵深处造成交通噪声污染，本文目的即预测交通噪声等效声级 $L_{eq}$ 沿 $x$ 轴的一维分布.

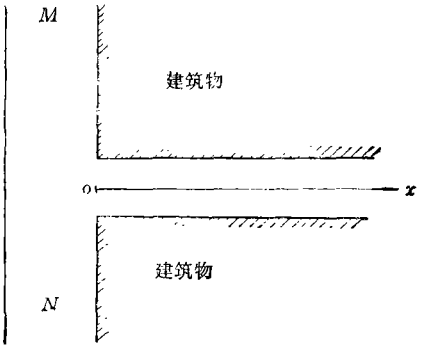


图 1　临街建筑分布

我们曾用计算机模拟方法对这一问题进行过研究. 用概率论方法在干道上建立起多种分布模型的随机车流，并在计算机上模拟产生这一车流；把每一机动车辆看成一个点声源，用几何声学的方法考虑直达声和多次反射声对 $ox$ 轴上测点的影响，将声级叠加计算求出测点上的统计声级预测值. 计算机模拟结果表明，在离巷口 25m 以内，预测值与实测值符合良好；沿巷子纵深距离越大，预测值误差越大. 原因是离巷口较近处，整个系统基本上是白色的. 首先对噪声源来讲，离巷口较近处交通噪声影响远大于其他各种背景噪声，总噪声基本上只由交通噪声决定，而计算机建立的随机车流模型较好地反映了交通噪声源的实际情况；其次，离巷口较近处声波反射次数较少，因此建筑物立面反射参数的无规则性所造成的影响亦少. 反

之，远离巷口处，背景噪声对测点影响所占的比重增大，而这一背景噪声不象交通噪声源那样容易建立概率模型；由于反射次数的增多，建筑参数无规则性带来的影响也愈明显．总之，离巷口愈远，系统愈趋向灰色．最终使物理方法逐渐失效．为此，本文用前面提出的 GM(1,1)模型对此问题进行研究．

**2.1** 原始序列 $y^{(0)}$ 的产生

可以用实测的方法在距巷口每隔一定间隔设一测点，至少 4—5 个，用声级计测出各测点交通噪声级，从而获得由 4—5 个数组成的 $y^{(0)}$ 原始序列．由于道路车流的随机性与不可重复性，所有测点上的声级必须一次同时测出，这就需要四、五只声级计，实际上较困难．对规划中的道路与建筑物，实测方法更不适用．

我们采用的计算机模拟方法能在计算机上重复产生同一随机车流．选择典型街道，观察车流状况参数及建筑环境参数，输入计算机，模拟得出离巷口 10 m 内 6 个测点上的噪声等效声级．由于离巷口较近处计算机模拟值与实测值十分吻合，故直接用求得的噪声级作原始序列，见表 1．

**2.2** GM(1,1) 预测模型解的计算

**表 1 原始序列与一次累加生成序列**

| 序号 $i$ | 坐标 $x$(m) | $y^{(0)}(i)$ | $y^{(1)}(i)$ |
|---|---|---|---|
| 1 | 0 | 68.52 | 68.52 |
| 2 | 2 | 67.92 | 136.44 |
| 3 | 4 | 67.66 | 204.10 |
| 4 | 6 | 67.01 | 271.11 |
| 5 | 8 | 66.40 | 537.51 |
| 6 | 10 | 66.08 | 403.59 |

将原始序列 $y^{(0)}$ 作一次累加生成处理，有

$$y^{(1)}(k)=\sum_{i=1}^{k}y^{(0)}(i) \qquad (8)$$

所得一次累加生成序列 $y^{(1)}$ 也列于表 1 中．将所得数据按(4)式建立矩阵 $\boldsymbol{B}$，由 (5) 式求出 $\hat{\boldsymbol{a}}$，由表 1 所列举的数据，可得

$$a=0.00773951 \quad u=68.823503$$

代入(7)式，即得 $y^{(1)}$ 序列的模型解

$$\hat{y}^{(1)}(k+1)=-8824.0e^{-0.00773951k}+8892.5 \qquad (9)$$

当 $k=1, 2, \cdots, 6$ 时分别表示 $x=0, 2, 4, \cdots, 10$m．将 $k>6$ 代入，即得 $\hat{y}^{(1)}$ 的灰色模型预测值．预测结果还不是噪声声级值，将 $\hat{y}^{(1)}$ 序列作一次累减生成

$$\hat{y}^{(0)}(i+1)=\hat{y}^{(1)}(i+1)-\hat{y}^{(1)}(i) \qquad (10)$$

累减生成序列 $\hat{y}^{(0)}$ 即为交通噪声等效声级沿 $x$ 轴分布的预测值．

需要指出的是，表 1 所列数值只是根据道路实际车流与建筑环境所作的一次模拟结果，因此由其出发的 GM(1,1) 预测值也只是一次模拟结果．由于随机车流的涨落，相同的车流状况与建筑参数输入量，可以产生不同的预测值．多次模拟的实践表明，各次模拟预测结果有涨落，但相互间差别不大．故实用中既可进行多次模拟后将各次结果取平均作为最终结果，也可只作一次模拟直接取作最终结果．

全部模拟计算工作由计算机完成，把 GM(1,1) 模型预测计算程序与原先使用的计算机模拟程序合并，只要在计算机中输入道路车流状况参数(车流量、轻重车等比率等等)及建筑参数(小巷宽度、建筑立面反射系数等)，计算机便能首先产生随机车流模型，求出离巷口较近处各测点上一组噪声值作为原始序列，然后按照上述 GM(1,1) 模型计算过程建立模型解，计算出 $\hat{y}^{(1)}$ 序列，作累减生成得 $\hat{y}^{(0)}$ 序列，最后自动输出按坐标分布的噪声预测值．

表 2 给出一典型实际环境下交通噪声沿小巷分布的实测值、计算机模拟方法预测值以及 GM(1,1) 方法预测值三者之间的比较．实测是在杭州市莫干山路三官弄进行的，两种模拟预测方法所输入的参量相同，均为在实测中观察记录的实际数据．从表 2 看出，在离巷口较近处，计算机模拟方法与实测值符合良好．在远离巷口处，GM(1, 1) 预测方法在很大程度上修正了计算机模拟方法的误差，使预测结果仍接近实测值．

共进行 4 次模拟，各次结果差别不大．距巷口 10m 以内，计算机模拟方法与 GM(1,1) 方法的结果一致；20m 处，计算机模拟方法误差

表 2　GM(1,1) 预测、计算机模拟预测、实测间的比较

| 坐标 $x$(m) | 噪声实测值 (dB) | 噪声预测值 (dB) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3 | | 4 | |
| | | 计算机 | GM(1,1) | 计算机 | GM(1,1) | 计算机 | GM(1,1) | 计算机 | GM(1,1) |
| 0 | 68.7 | 68.4 | 68.4 | 68.5 | 68.5 | 67.8 | 67.8 | 68.5 | 68.5 |
| 5 | 67.1 | 66.8 | 66.8 | 67.0 | 66.8 | 66.3 | 66.3 | 67.3 | 67.2 |
| 10 | 66.4 | 66.0 | 66.0 | 66.1 | 65.8 | 65.4 | 65.2 | 66.0 | 65.9 |
| 20 | 62.7 | 64.2 | 63.5 | 64.3 | 63.2 | 63.6 | 62.7 | 64.3 | 63.1 |
| 30 | 60.1 | 62.4 | 61.3 | 62.6 | 60.6 | 62.0 | 60.3 | 62.5 | 61.0 |
| 40 | 58.6 | 61.4 | 59.1 | 61.3 | 58.2 | 60.5 | 58.0 | 61.1 | 59.1 |

略大于 1dB,模型仍为有效;到 40m 处，计算机模拟方法与实测值误差达近 3dB, 而 GM(1,1) 方法与实测比较,在 20m 处误差在 0.5dB, 40m 处误差仍保持在这一水平上，可见此模型确实十分有效.

## 3　模型的精度检验

GM(1,1) 模型有多种精度检验方法,本文采用后验差检验，所用检验指标为后验差比 $C$ 和误差概率 $p$, 计算方法如下

$$C = S_2/S_1$$

$$p = p\{|q(k)| < 0.6745S_1\}$$

其中，$q(k) = y^{(0)}(k) - \hat{y}^{(0)}(k)$ 为残差，$S_1$ 为 $y^{(0)}(k)$的均方差，$S_2$ 为 $q(k)$ 的均方差. 表 3 为后验差检验表. 作为例子，仅对第 4 次模拟结果进行检验，把建模过程有关数据列于表 4. 由表 4 所列数据计算得 $C = 0.122, p = 1$，由后验差检验表可知,模型精度是好的,为一级.

表 3　后验差检验表

| 预测精度等级 | $p$ | $C$ |
|---|---|---|
| 1 好 | >0.95 | <0.35 |
| 2 合格 | >0.8 | <0.5 |
| 3 勉强 | >0.7 | <0.45 |
| 4 不合格 | ≤0.7 | ≥0.65 |

## 4　小结

交通噪声沿建筑群纵深方向传播引起噪声污染，建立噪声在传播途径上噪声级沿坐标分布的预测模型，对于城市规划中减少与防治噪声污染,具有重要意义.

表 4　原始序列、预测值和残差

| 序号 $i$ | 坐标 $x$(m) | $y^{(0)}(i)$ | $\hat{y}^{(0)}(i)$ | $q(i)$ |
|---|---|---|---|---|
| 1 | 0 | 68.52 | 68.52 | 0 |
| 2 | 2 | 67.92 | 68.03 | −0.11 |
| 3 | 4 | 67.66 | 67.50 | 0.16 |
| 4 | 6 | 67.01 | 66.99 | 0.02 |
| 5 | 8 | 66.40 | 66.47 | −0.07 |
| 6 | 10 | 66.08 | 65.96 | 0.12 |

在小巷纵深方向距道路车辆流较近处，整个系统为白色，可用基于物理模型的计算机模拟方法来预测;纵深方向距离较远处,系统趋向灰色,改用 GM(1,1) 模型进行预测,与实测对比及精度检验结果,都表明此模型十分有效.

现在有关灰色理论预测的文献多为本征灰色系统时间序列预测. 本文表明这一理论同样适用于非本征灰色系统中物理量关于坐标分布的预测. 这为灰色系统理论在环境预测中的应用提出了一条新的思路.

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# Abstracts

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**Study of Furfural Residue Carbon for Eliminating and Recovering Sulphur Dioxide from Flue Gases.** Cai Guangyu et al. (Dalian Institute of Chemical Physics, Academia Sinica, Dalian 116023): *Chin J. Environ. Sci.*, 14(2), 1993, pp. 2—6

A new type of modified active carbon, furfural residue carbon was manufactured with residues in the production of furfural. Its physical and chemical properties were characterized with TPDE, GC-MS, BET, steady and flowstate adsorption, oxidation of $SO_2$, and compared with those of other commercial active carbons. It was found that the furfural residue carbon possesses a better desulphurization property without the need of adding any active components, and is applicable to the process of desculphurization from flue gas to prepare sulphuric acid. It was supposed that the surface groups composed of hydroxyl and carbonyl are the active centers of $SO_2$ uptake, and the abundant middle pores are favourable to the diffusion of reactants. The furfural residue carbon made on an industrial scale was examined successfully on a pilot plant capable of treating 5000 $Nm^3/h$ flue gas from a coal-combustion power plant, at an inlet temperature of about 70°C and 1500—2500 ppm of $SO_2$ concentration of flue gas and with a space velocity of 500 h. Stability test was carried out for more than 6000 hours, and it was found that the conversion of $SO_2$ reached about 70%, the concentration of by-product $H_2SO_4$ was about 30%wt and no apparent deactivation of the furfural residue carbon was observed. In addition, production cost of the furfural residue carbon is about 40% lower than the commericial active carbon containing iodine component.

**Key words:** active carbon, flue gas, sulphur dioxide, desulphurization.

**Studies on the "Yichang" Synthetic Sorbent for Sulfur Dioxide removal in Fluidized Bed Combustion of Coal.** Li Zhijiang et al. (Thermal Engineering Department Tsinghua University, Beijing 100084): *Chin. J. Environ. Sci.*, **14**(2), 1993, pp. 7—10

As an alternative to natural limestone for sulfur dioxide removal in fluidized bed combustion of coal, an advanced synthetic sorbent was developed in Tsinghua University and a pilot manufacture with output of 5000 tons per year has been set up in Yichang city, Hubei province, China. Plant tests ware conducted on 3 fluidized bed boilers with steam capacities of 6,10 and 10t/h under 7 operating conditions. The technique for the production of "Yichang" sorbent is described; the characteristics of "Yichang" sorbent, such as composition, pore size distribution, microstructure, strength, water-tolerance and sulfur capture capacity are demonstrated; and results of plant tests are presented and discussed. Finally, the technology is economically analyzed and compared with other sulfur removal methods.

**Key words:** sulfur dioxide, limestone, desulfurization, fluidized bed combustion.

**Study on Entrapping Agents for Immobilizing Microbial Cell.** Jiang Yuhong, Huang Xia and Yu Yuxin (Dept. of Environmental Engineering, Tsinghua University, Beijing 100084): *Chin. J. Environ. Sci.*, **14** (2), 1993, pp. 11—15

Entrapping methods with agar, gelatine, calcium alginate, polyvinyl alcohol and acrylamide gels as entrapping agents for immobilizing microbial cell were studied. By comparing their characteristics, caicium alginate and polyvinyl alcohol gels were found to be the most suitable entrapping agents for their high mechanical stability, good mass diffusivity, less toxicity and easiness in entrapping operation.

**Key words:** immobilized microbial cell, entrapping agent, calcium alginate, polyvinyl alcohol.

**Prediction of One-Dimension Distribution of Traffic Noise among Road-Side Buildings with Grey System Model.** Zhang Bangjun, Pan Zhonglin et al. (Dept. of Physics, Hangzhou University, Hangzhou 310028):

*Chin. J. Environ. Sci.*, **14**(2), 1993, pp 16—19

Because of too many unknown factors in the propagatio of noise, the prediction of noise distribution by using conventional physical model is not very accurate at distant observation-points from sound source. A gray system model for the prediction of noise propagation given in this paper was proposed. At first the general GM(1,1) model describing one-dimentional distribution of physical parameters in non-intrinsic grey system is given, then the initial data are produced by computer simulation in the effective scope of he model, finally, the pridection data of gray model are obtained. The predicted results of GM(1,1) method at distant observation points are more accordant with measured data than those obtained with by computer simulation.

**Key words:** traffic noise, noise distribution, gray system model.

**Oxidation of $SO_2$ on the Surface of Particles in the Atmosphere.** Zhu Lianxi, Jiang Wenju et al. (Dep. of Environ. Sci. and Eng. Chengdu University of Science and Technology, Chengdu 610065): *Chin. J. Environ. Sci.*, **14**(2), 1993, pp. 20—24

The oxidation of $SO_2$ on the surface of seven kinds of single particles, four kinds of fly ashes from different sources and six air particle samples from different cities were studied. The ability of the oxidants to accelerate the oxidation of $SO_2$ is in the following order: $MnO_2 > Mgo > CaO > Fe_2O_3 > Al_2O_3 > V_2O_5 > SiO_2$. The oxidation ability of fly ashes is closely related to the content of strong oxidants and alkaline compounds in the particles. The order of the sources of particles in their ability to accelerate the oxidation of $SO_2$ is metallurgical fly ash > civilian use coal fly ash > building material fly ash > industry use coal fly ash. For air particle samples at different cities in Sichuan, the order is: Yibin > Zigong > Chongging > Emeshan > Leshan > Chengdu. This results provide scientific basis for understanding the causes of Sichuan acid rain and countermeasure for acid rain control.

**Key words:** $SO_2$, acid rain, surface oxidation, $SO_2$.

**Study on Combined Effects of High Dosages of Selenium and Cadmium Fed to Rats on GSH-px Activities in Blood and Tissues.** Lu Wenqing, Yang Chengfeng et al. (Dept. of Environ. Health, Tongji Medical University, Wuhan 430030): *Chin. J. Environ. Sci.*, **14**(2), 1993, pp. 25—27

The artificial synthesis diets were fed to SD rats for 12 weeks to examine the combined effects of high dosages of selenium(5.5mg/kg) and cadmium (20.4 mg/kg) on GSH-px activities in blood and tissues (heart, liver, kidney, lung, brain and spleen). The results showed that the blood GSH-px activities of rats fed ordally with high dosages of selenium and cadmium together increased significantly, and the decrease in blood GSH-px activities in rats fed orally with a high dosage of selenium or cadmium alone was antagonized. The decreases in GSH-px activities of liver, kidney, lung and spleen due to feeding orally with a high dosage of selenium or cadmium alone were antagonized by feeding orally with high dosages of selenium and cadmium simultaneously. But the administering orally with high dosages of selenium and cadmium led to a significant decrease in GSH-px activites in rats brain.

**Key words:** selenium, cadmium, GSH-px activity, rat toxicological experiment.

**Study on Sodium Alginate and Polyvinyl Alcohol as Entrapping Agents.** Wu Xiaolei, Liu Jianguang et al. (Dept. of Environ. Eng. Tsinghua University, Beijing 100084): *Chin. J. Environ. Sci.*, **14**(2), 1993, pp. 28—31

In this study, two materials, namely, sodium alginate and polyvinyl alcohol (PVA) were used as entrapping agents to produce immobilized microbial beads. Through orthogonal test, the optimal conditions of entrapping were determined for the two agents by using TOC removal efficiency as the primary criterion and bead strength as the auxiliary criterion. Comparisons were also made ber-