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Projection pursuit model of vehicle emission on air pollution at intersections based on the improved bat algorithm

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Abstract: The projection pursuit model is used to study the assessment of air pollution caused by vehicle emissions at intersections. Based on the analysis of the characteristics and regularities of vehicle emissions at intersections, a vehicle emission model based on projection pursuit is established, and the bat algorithm is used to solve the optimization function. The research results show that the projection pursuit model can not only measure the air pollution of vehicle emissions at intersections, but also effectively evaluate the level of vehicle exhaust emissions at intersections. Taking the air pollution caused by vehicle emissions at intersections as the research object and considering the influence factors of vehicle emissions on air pollution comprehensively, the evaluation index system of vehicle emissions at intersections on air pollution is constructed. Based on large data analysis, a prediction model of air pollution caused by vehicle emissions at intersections is constructed, and an improved bat algorithm is used to realize the assessment process. The application results show that the prediction model of vehicle emissions at intersections can define the degree of air pollution caused by vehicle emissions, and it has good guiding significance and practical value for solving the problem of air pollution caused by vehicle emissions.

Key words: intersection; vehicle emission; pollutants; projection pursuit; bat algorithm

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Vehicle emission contains hydrocarbons (C_nH_m), carbon monoxide (CO), nitrogen oxides (NO_x), lead (Pb), sulfur dioxide (SO_2) and particulate matter (PM), and many of which are damaging the health of humans[1-2]. Hence, how to monitor and reduce air pollution caused by vehicle emissions effectively has become one of the hot issues of current research. In order to monitor vehicle emission factors and total emissions, some effective emission analysis models have been proposed. MOBILE is a classic macroscopic emission analysis model, which is typically used to estimate vehicle emissions according to the average speed in the wide-area[3-4]. Kheirbek et al.[5] estimated $PM_{2.5}$-attributable mortality and morbidity from on-road vehicle generating air pollution in New York City using high-spatial-resolution emissions estimates. Doolan and Muntean[6] presented a novel approach to reduce vehicle emissions—EcoTre. Schneidemesser et al.[7] found the significant potential for NO_2 reductions. The research on vehicle emission in China has also achieved certain results. Zhao et al.[8] derived pollutant mission factors from mixed vehicles, cars, and taxis. ETC (electronic toll collection) testing shows that the design satisfies severe emission regulations with greater sustainable and environmentally friendly practical application[9]. In fact, when calculating the emission of urban motor vehicles, although the research scope of vehicle emission models in China has gradually shifted from laboratory to real road emissions, there are relatively few achievements in this field. Therefore, this paper focuses on the evaluation of vehicle emissions pollution at urban intersections.

Projection pursuit (PP) is a new statistical method for processing and analyzing high-dimensional data. It has been applied in many fields, such as environmental quality assessment, atmospheric science and water conservancy planning. Jiang et al.[10] presented a general approach for coherency detection in bulk power systems using the PP theory. Pires et al.[11] developed an expansion of space-distributed time series by statistically independent uncorrelated sources. In this paper, the projection pursuit model based on the improved bat algorithm is proposed to evaluate and analyze air pollution caused by vehicle emissions at intersections.

1 Measurement Index for Vehicle Emission Pollution at Intersections

Vehicle exhausts contain more than 100 different compounds. The main pollutants are harmful substances such as C_nH_m, CO, NO_x, Pb, SO_2 and PM, as well as sec-

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ondary pollutants produced by photochemical reactions[12]. The main atmospheric pollutants at intersections are shown in Tab. 1.

Tab. 1 Measurement index of vehicle emissions on air pollution

Pollutants	First level index	Secondary level index
Gas pollutants	CO_x	I_1
	THC	I_2
	NO_x	I_3
	SO_x	I_4
Secondary derivative pollutants	CO_2	I_5
	NO	I_6
	SO_2	I_7
Solid pollutants	Pb	I_8
	$PM_{2.5}$	I_9
	PM_{10}	I_{10}
	TSP	I_{11}

2 Projection Pursuit Model of Vehicle Emission at Intersections

In this section, based on the projection pursuit algorithm, we establish the projection pursuit evaluation model of vehicle emissions on air pollution at intersections.

Suppose that the measured value of intersection i is x_{ij} ($i = 1, 2, \ldots, n; j = 1, 2, \ldots, m$) under the measurement index j; n is the number of intersections; m is the number of indicators for the emissions of air pollution to the vehicle, and then we obtain the original matrix $\boldsymbol{X} = (x_{ij})_{n\times m}$. The algorithm for the model is as follows:

Step 1 Normalization of sample data for air pollution at intersections. We normalize the sample data by the following formula before modeling:

$$y_{ij} = 1 - x_{ij} \cdot [\max x_{ij} + \min x_{ij}]^{-1} \tag{1}$$

Suppose that $\boldsymbol{a} = \{a_1, a_2, \ldots, a_3\}$ is the unit projection vector, and then y_{ij} is an intersection-dimensional eigenvalue Z_i.

$$z_i = \sum_{j=1}^{m} a_j y_{ij} \tag{2}$$

Step 2 The projection index function of vehicle emissions on air pollution at intersections. The inter-class distance function for the assessment of air pollution by vehicle emissions at intersections is defined as:

$$f_1(\boldsymbol{a}) = \left[\frac{1}{n-1}\sum_{i=1}^{n}\left(z_i - \sum_{i=1}^{n}\frac{z_i}{n}\right)^2\right]^{0.5} \tag{3}$$

The inter-class density function for the assessment of air pollution by vehicle emissions at intersections is defined as:

$$f_2(\boldsymbol{a}) = \begin{cases} \sum_{i=1}^{n}\sum_{k=1}^{n}(m - r_{ik}) & m - r_{ik} \geqslant 0 \\ 0 & m - r_{ik} < 0 \end{cases} \tag{4}$$

where r_{ik} is the distance between $\boldsymbol{Z}_i$ and $\boldsymbol{Z}_k$, $r_{ik} = \|\boldsymbol{Z}_i - \boldsymbol{Z}_k\|, i = 1, 2, \ldots, n; k = 1, 2, \ldots, n$.

The projection index function of vehicle emissions about air pollution at intersections is obtained:

$$F(\boldsymbol{a}) = f_1(\boldsymbol{a}) \cdot f_2(\boldsymbol{a}) \tag{5}$$

Step 3 Optimized projection index function of vehicle emissions on air pollution at intersections. The objective function of vehicle emissions on air pollution at intersections is as follows:

$$\max F(\boldsymbol{a}) = f_1(\boldsymbol{a}) \cdot f_2(\boldsymbol{a}) \tag{6}$$

$$\text{s.t.} \quad \sum_{j=1}^{n} a_j^2 = 1 \tag{7}$$

Step 4 Comprehensive pollution index for assessment of air pollution by vehicle emissions at intersections. We regard $w = \{a_1^2, a_2^2, \ldots, a_m^2\}$ as the weight coefficient of each evaluation index and construct the comprehensive pollution index for the assessment of air pollution by vehicle emissions at intersections as

$$F(\text{cross}) = \sum_{j=1}^{m} a_j^2 y_{ij} \tag{8}$$

3 Projection Index Function based on Improved Bat Algorithm

Projection function optimization plays a deciding role in the success of the projection pursuit model. In this section, we apply the improved bat algorithm to the projection function optimization to assess the air pollution caused by vehicle emissions and obtain the optimal solution of the evaluation model.

In order to prevent the search solution from falling into the local optimal solution, the updated formulas for loudness A_i and rate r_i of pulse emissions are as follows:

$$A_i^{t+1} = A_i^t \frac{\beta_i}{\alpha} \exp(-0.1t) \tag{9}$$

$$r_i^{t+1} = r_i^t \left(1 - \frac{A_i^t}{A_i^{t+1}}\right) \tag{10}$$

where α is the attenuation coefficient of loudness and it usually defaults to 0.9; $\beta_i \in [0, 1]$ represents a random attenuation coefficient of loudness that obeys uniform distribution. The search update formula is as follows:

$$Q = 1 - \exp(-|p - f_{\max}|)\boldsymbol{\delta}_i \tag{11}$$

$$X_i^t = wX_i^{t+1} + (g - X_i^{t-1})Q + (k - X_i^{t-1})(1 - Q) \tag{12}$$

where Q is the adaptive step size factor; P is the average of the fitness values obtained each time; $\boldsymbol{\delta}_i$ is a random vector that obeys uniform distribution; X_i^t is the current global optimal position; g is the temporary location (solution) which is always obtained by a random vector based on X_i^t. In order to increase the randomness for easily jumping out of the local optimum, a random-weight value w is used as the weight coefficient of X_i^{t+1} when updating the location. k is the best solution after each optimization.

4 Case Analysis

In this section, 10 intersections (recorded as cross_1, cross_2, …, cross_{10}) in a specific area of Nanjing are taken as the study object. The monitoring value of 10 intersection was obtained by field data collection (see Tab. 2). The monitoring values of each indicator of 10 crossings are substituted into the evaluation model.

Tab. 2 Monitoring data of 10 intersections of Nanjing city mg/m^3

Name	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9	I_{10}	I_{11}
Cross_1	0.234 1	0.233 5	0.561 2	0.345 6	0.101 1	0.280 7	0.821 1	0.233 4	0.678 9	0.543 1	0.254 6
Cross_2	0.373 4	0.267 1	0.557 1	0.405 1	0.201 9	0.290 7	0.763 1	0.244 5	0.680 3	0.540 9	0.235 6
Cross_3	0.366 5	0.276 6	0.567 8	0.388 1	0.123 1	0.360 1	0.810 7	0.301 1	0.657 3	0.601 3	0.345 7
Cross_4	0.476 3	0.365 4	0.389 1	0.390 2	0.123 5	0.350 1	0.823 1	0.321 1	0.645 1	0.497 3	0.478 2
Cross_5	0.771 1	0.276 8	0.581 7	0.378 1	0.200 1	0.341 2	0.822 1	0.345 1	0.700 1	0.498 1	0.346 5
Cross_6	0.235 6	0.378 8	0.662 1	0.378 9	0.123 1	0.312 2	0.791 3	0.345 7	0.599 3	0.651 3	0.236 5
Cross_7	0.435 1	0.235 1	0.399 1	0.345 1	0.200 3	0.321 4	0.800 1	0.309 7	0.700 4	0.734 1	0.346 7
Cross_8	0.678 1	0.276 4	0.789 1	0.560 1	0.213 1	0.301 1	0.789 9	0.346 8	0.698 1	0.467 3	0.349 1
Cross_9	0.346 7	0.337 1	0.892 3	0.472 1	0.273 1	0.234 4	0.790 9	0.290 7	0.598 4	0.567 9	0.610 1
Cross_{10}	0.356 7	0.238 1	0.237 5	0.274 1	0.245 1	0.234 1	0.801 1	0.290 8	0.701 6	0.602 3	0.291 7

4.1 Fitness curves of projection vectors function

According to the bat algorithm of the projection function proposed in Section 3, the search process based on the improved bat algorithm and the standard bat algorithm is implemented on the Matlab platform. We first use the PSO algorithm to solve the proposed mode, and then use the BA algorithm to solve the proposed model. After the iteration of the operation, the curves of projection vector fitness are obtained, as shown in Fig. 1.

As can be seen from Fig. 1, the improved BA is better than the standard BA and PSO in the optimization result.

4.2 Error comparison between three algorithms

In this section, we will calculate the assessment error of the pollutant emissions from 10 intersections under the three algorithms and the measured data to verify the effectiveness and superiority of the proposed improved bat algorithm. The results are shown in Tab. 3.

It can be seen from Tab. 3 that the average error rate of the projection pursuit analysis model is 6.098 6% using the PSO algorithm. Therefore, in terms of accuracy, the IBA is better than the PSO and the standard BA, and it is feasible for assessing the air pollution.

5 Conclusions

1) The impact of vehicle emissions on air pollution is effectively evaluated and analyzed. A projection pursuit model is also proposed based on the improved bat algorithm.

2) The results of the case analysis show that the proposed model is superior to the standard BA in convergence speed and recognition accuracy.

3) This paper provides a theoretical basis and technical support for improving urban air quality and building low-carbon transportation. It also provides a novel method and ideas for vehicle emissions-related research.

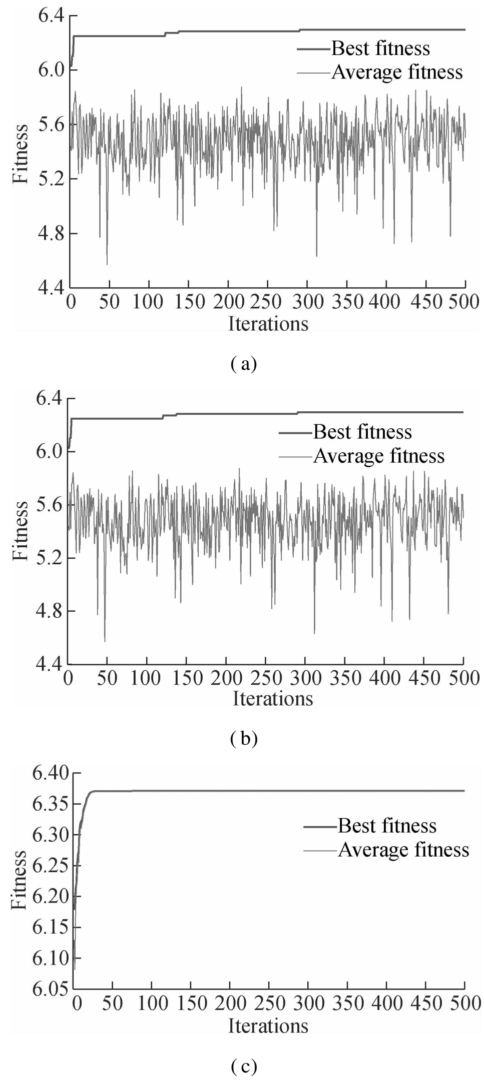

Fig. 1 Curves of projection vector fitness. (a) PSO; (b) Improved BA; (c) Standard BA

Tab. 3 Comparison of error rates using different optimization algorithms %

Name	IBA	Standard BA	PSO
$Cross_1$	0.58	13.94	5.89
$Cross_2$	0.85	9.79	2.57
$Cross_3$	0.41	9.51	2.63
$Cross_4$	5.74	6.27	0.42
$Cross_5$	0.87	0.48	7.86
$Cross_6$	0.10	13.09	5.87
$Cross_7$	2.74	12.19	9.14
$Cross_8$	6.54	0.83	10.94
$Cross_9$	3.70	3.71	0.28
$Cross_{10}$	10.46	16.40	15.39

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基于改进蝙蝠算法的交叉口车辆排放对空气污染的投影寻踪模型

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摘要:利用投影寻踪模型研究交叉口车辆排放对大气污染评估的监测问题. 在分析交叉口机动车排放特性和规律基础上,建立基于投影寻踪的机动车排放模型,并利用蝙蝠算法进行优化函数求解研究. 研究结果表明投影寻踪模型不但能够测定车辆排放对交叉口大气污染问题,而且能有效评估交叉口汽车尾气排放水平. 以交叉口车辆排放对大气污染为研究对象,在综合考虑车辆排放对大气污染影响因素的基础上,构建了交叉口车辆排放对大气污染的评估指标体系. 通过大数据分析,构建了交叉口车辆排放对大气污染的预测模型,并利用改进的蝙蝠算法实现评估过程. 应用结果表明,交叉口车辆排放的预测模型能界定车辆排放对大气的污染程度,而且对解决车辆排放对大气污染有较好的指导意义和实用价值.

关键词:交叉口;车辆排放; 污染物; 投影寻踪; 蝙蝠算法

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