A PSO-based Model for Assessment of Atmospheric Quality

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Summary
The assessment for atmospheric quality has become the key problem in the study of the quality of atmospheric environment. Supposing the values of parameters of the universal formula for calculating the harm rate of the atmospheric pollution are uniform for different pollutants, the particle swarm optimization (PSO) algorithm is applied to optimize the parameters of the universal formula. We proposed a model based on the particle swarm optimization (PSO) algorithm, which suited to multi-pollutants for assessment of atmospheric quality in this paper. Experimental results show the advantages of the proposed model, such as pellucid principle and physical explication, predigested formula and low computation complexity. Therefore the proposed model in this paper could provide an effective approach for environmental renovation planning and has great potential in the field of the atmospheric quality assessment.
Key words:
Particle swarm optimization, universal formula, pollution harm rate, assessment model.

Introduction

The air environment is closely linked with human health and life, whereas the atmospheric quality has been deteriorating with the quickening rhythm of economic growth and industrialized progress. The problems regarding the atmospheric pollution have attracted more and more attention recently. Therefore the studies related the atmospheric quality, such as the assessment and forecasting of the atmospheric quality, have become noticeable increasingly.

In order to control the atmospheric pollution, many methods have been proposed and used to evaluate the atmospheric quality, such as algorithms based on grayer clustering, fuzzy mathematics and step analysis, and some others. But there is an obvious limitation that the assessment process and assessment results are lack of specific physical meaning when using these methods. In general, it is difficult to provide directly scientific basis for environmental renovation planning. A model based on the particle swam optimization (PSO) algorithm is proposed to evaluate the grade of atmospheric pollution in this paper. Experimental results show that the proposed model is feasible and affective, which has the characters of pellucid principle and physical explication. Moreover, the simplification is the important advantage of the model for atmospheric quality assessment.

2. Brief introduction to PSO

Particle swarm optimization (PSO) is originally developed by Kennedy and Elberhart[1-2], which is a method for optimizing hard numerical functions on metaphor of social behavior of flocks of birds and schools of fish. A swarm consists of individuals, called particles, which change their positions over time. Each particle represents a potential solution to the problem.

Let the ith particle in a D-dimensional space be represented as $X_i = (x_{i1}, x_{i2}, \ldots, x_{id})$ $(i=1,2,\ldots,m)$. The best previous position (which possesses the best fitness value) of the ith particle is denoted by $P_i = (P_{i1}, P_{i2}, \ldots, P_{iD})$, which is also called P_{best}. The index of the best P_{best} among all the particles is represented by the symbol g. The location P_g is also called g_{best}. The velocity for the ith particle is represented as $V_i = (V_{i1}, V_{i2}, \ldots, V_{iD})$. The concept of the particle swarm optimization consists of, at each time step, changing the velocity and location of each particle towards its P_{best} and g_{best} locations according to Eqs.(1) and (2), respectively[3-6]:

$$v_{id} = w\, v_{id} + c_1 r_1 (p_{id} - x_{id}) + c_2 r_2 (P_{gd} - x_{id}), \quad (1)$$

$$x_{id} = x_{id} + v_{id}. \quad (2)$$

Where w is the inertia coefficient which is a constant in the interval [0,1] and can be adjusted in the direction of linear decrease; c_1 and c_2 are learning rates which are nonnegative constants; r_1 and r_2 are generated randomly in the interval [0,1]; $v_{id} \in [-v_{max}, v_{max}]$, and v_{max} is a designated maximum velocity. The termination criterion for iterations

Table 1: The values of c_{i0}, c_{i1}, c_{i2}, c_{i3}, c_{i4} and x_i of seven pollutants

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pollutant	0th grade		1st grade		2nd grade		3rd grade		4th grade	
	c_{i0}	x_{i0}	c_{i1}	x_{i1}	c_{i2}	x_{i2}	c_{i3}	x_{i3}	c_{i4}	x_{i4}
SO_2	0.02	1	0.05	2.50	0.15	7.50	0.25	12.5	0.50	25.0
NO_X	0.015	1	0.05	3.33	0.10	6.67	0.15	10.0	0.30	20.0
NO_2	0.015	1	0.04	2.67	0.08	5.33	0.12	8.00	0.25	16.7
FM_{14}	0.02	1	0.05	2.50	0.10	5.00	0.25	12.5	0.50	25.0
TSP	0.05	1	0.12	2.40	0.30	6.00	0.50	10.0	1.20	24.0
CO	0.50	1	1.50	3.00	4.00	8.00	6.00	12.0	10.0	20.0
Fallen dust	2.00	1	5.50	2.75	12.0	6.00	24.0	12.0	40.0	20.0

is determined according to whether the maximum generation or a designated value of the fitness is reached.

3. Universal formula for calculating harm rate of atmospheric pollution

3.1 The formula of harm rate of the *i*th atmospheric pollutant

The harm rate of pollution of the *i*th atmospheric pollutant can be expressed as[7]:

$$R_i = 1/(1+a_i e^{-b_i c_i}) , \quad (3)$$

where a_i and b_i are parameters related to the *i*th pollutant, and c_i is the measured density of the *i*th pollutant. Parameter c_i can be replaced with a relative density, namely, $x_i = c_i / c_{i0}$, where c_{i0} is a predefined parameter of the *i*th pollutant, usually taken as the natural basic density of the *i*th pollutant. Then Eq.(3) can also be rewritten as:

$$R_i = 1/(1+ae^{-bx_i}) . \quad (4)$$

By using the relative density, a_i and b_i can be regarded as that they are irrelative with the characteristics of the pollutant. Thus Eq. (4) is also suitable to the cases of multi-pollutants.

To generalize the applicability of the model, a universal parameter t is introduced in Reference [8], which is needed to be ascertained unrelated to the *i*th pollutant in Eq. (4). Then it follows that

$$R_i = 1/(1+ae^{-bx_i})^t . \quad (5)$$

3.2 Optimization of parameters using PSO method

Denote c_{i0} as the benchmark value of a special atmospheric pollutant, c_{i4} the limiting value of obvious pollution density and c_{i1}, c_{i2} and c_{i3} the limiting values of standard densities regulated by "Environment Air Quality Standard (GB3095-1996)", respectively. Therefore the relative value at each level x_{ik} (k=0,1,2,3,4) can be calculated:

$$x_i = c_i / c_{i0} . \quad (6)$$

The values of c_{i0}, c_{i1}, c_{i2}, c_{i3}, c_{i4} and x_i of seven pollutants are listed in Table 1.

In order to use the PSO method to optimize parameters in Eq. (5), the objective function is selected as follows:

$$\min f(x) = \min\{(\sum_{k=0}^{K}\sum_{i=0}^{m}(R_{ik}-R_{ke})^2)/(Km)\} , \quad (7)$$

where m is the number of the selected pollutants; K is the number of the atmospheric pollution levels; R_{ik} is the harm rate of atmospheric pollution of the *i*th pollutant for level k, and R_{ke} is the objective value of the harm rate of atmospheric pollution for level k, respectively. The values of m and K are taken as 7 and 5, respectively, in this paper. According to the index grading principle of geometric proportion evaluating and arithmetical classifying, the objective values of harm rate of atmospheric pollution for the five levels can be obtained as 0.01, 0.0463, 0.1284, 0.3562, and 0.99 [7].

In the process of optimizing parameters in Eq.(7) by using the PSO, we find that the values of parameters are changed obviously with the differences of the intervals of the parameters in PSO as shown in Table 2. Moreover, the value of a is approached to the lower limit of the interval. Thus the function relation between the harm rate of atmospheric pollution and the relative densities of pollutants can be set up by two parameters approximately. So parameter t is eliminated and Eq. (4) is still used as the calculating formula of the harm rate of atmospheric pollution.

The optimal values of parameters a and b obtained by using the PSO are 63.93 and 0.3401, respectively.

Table 2: The Ranges of *a*, *b* and *c* for different PSO parameters

Ranges of PSO parameters	[-120, 120]	[-200, 200]	[-1000, 1000]	[-3000, 3000]
a	119.99656	199.99138	999.98409	2999.99
b	0.354625	0.378879	0.460297	0.51896
c	0.824222	0.728762	0.533039	0.45053

3.3 Universal formula of harm rate of atmospheric pollution suited to multi-pollutants

According to the optimal values of parameters a and b obtained and Eq.(4), therefore the calculating formula of harm rate of atmospheric pollution suited for the cases of multi-pollutants can be formulized generally as:

$$R_i = 1/(1+63.93e^{-0.3401x_i}) . \quad (8)$$

4. A PSO-based model for assessment of atmospheric quality

After obtaining the harm rate R_i then the assessment for the atmospheric quality can be performed. But how to integrate different R_i is a key problem. A comprehensive method is proposed in [7] for the assessment of atmospheric quality with multi-pollutants. Based on this method, the optimization is performed here by using PSO algorithm. Define a variable R to represent the comprehensive harm rate of atmospheric pollution. The final formula for the assessment of atmospheric quality can be illustrated as follows:

$$R = \sum_{i=1}^{m} w_i R_i = \sum_{i=1}^{m} w_i (1/(1+63.93e^{-0.3401x_i})) . \quad (9)$$

Where m is the number of the types of pollutants, R_i is the harm rate of atmospheric pollution of the ith pollutant, w_i is the normalized weight value of the ith pollutant, respectively. Parameter w_i can be defined by w_k' which is the relative importance of the corresponding level of k. The values of w_k' are[9]: $w_0'=0$, $w_1'=1$, $w_2'=1.67$, $w_3'=2.33$, $w_4'=3$. Then w_i can be formularized as follows:

$$w_i = v_i \Big/ \sum_{j=1}^{m} v_j \; , \quad (10)$$

where v_j is the relative importance of the jth pollutant, namely, $v_j = w_k'$ if R_j ranked as k level.

The atmospheric quality could be assessed according to the value of R if it is known. The harm rate of pollution in each level of each atmospheric pollutant could be calculated according to Table 1 and Eq.(8). Taking the average of the same level of all atmospheric pollutants as the standard pollution harm rate value of the corresponding level, the ranges of R of all the five levels can be obtained and listed in Table 3.

Table 3: The Ranges of R for five assessment levels

Grades (k)	0^{th} grade excellent	1^{st} grade good	2^{nd} grade slight	3^{rd} grade moderate	4^{th} grade serious
Ranges of R	[0.0, 0.0215]	[0.0216, 0.0383]	[0.0384, 0.1245]	[0.1246, 0.4056]	[0.4057, 0.939]

5. Examples for assessment atmospheric quality

The real monitoring density values of the three main pollutants (PM10, SO_2 and NO_2) in a city of Northeast of China are selected as the sample data. Considering the windy and sandy characteristics, and the notable pollution in spring in this city, we select the sample data from 1 April 2002 to 30 April 2002. The assessment results calculated by the proposed PSO-based method are listed in Table 4. Satisfactory results in the table show that the proposed PSO-based model is effective and applicable for the assessment of atmospheric quality.

It could be found from Table 4 there are only two results are slightly different with the given real data. Moreover the possibility can't be excluded that there may be some errors in the practical measurement for the equipment, in the observation or of some other objective reasons. Therefore it could be included that the proposed PSO-based method for the assessment of atmospheric quality is effective and applicable.

6. Conclusions

Simulations show that the proposed model based on PSO algorithm is feasible and effective for the assessment of atmospheric quality. Because the values of parameters a and b for calculating the harm rate of the atmospheric pollution are uniform for different pollutants, the proposed method could have more advantageous when the number of pollutant types is large. Since the assessment of the atmospheric quality is performed according to the density values of multi-pollutants and the assessment criterion is according to the average density of multi-pollutants, the assessing process is more objective and has clear physical meaning. The proposed model developed in this paper that could be useful in the field of the atmospheric quality assessment.

Table 4: Assessment results of a city of Northeast of China

Date	Harm rate R	Assessment	Real results
2002.4.1	0.04204	good	good
2002.4.2	0.03487	good	good
2002.4.3	0.04008	good	good
2002.4.4	0.02570	good	good
2002.4.5	0.03200	good	good
2002.4.6	0.02600	good	good
2002.4.7	0.02920	good	good
2002.4.8	0.02590	good	good
2002.4.9	0.07440	slight	slight
2002.4.10	0.02970	good	good
2002.4.11	0.02560	good	good
2002.4.12	0.04110	slight	slight
2002.4.13	0.02680	good	good
2002.4.14	0.03360	good	good
2002.4.15	0.02730	good	good
2002.4.16	0.03050	good	good
2002.4.17	0.04270	slight	slight
2002.4.18	0.03020	good	good
2002.4.19	0.02720	good	good
2002.4.20	0.02490	good	good
2002.4.21	0.23550	moderate	serious
2002.4.22	0.14810	moderate	moderate
2002.4.23	0.02760	good	good
2002.4.24	0.02340	good	good
2002.4.25	0.03240	good	good
2002.4.26	0.03880	slight	slight
2002.4.27	0.04320	slight	slight
2002.4.28	0.02890	good	good
2002.4.29	0.02600	good	good
2002.4.30	0.03960	slight	good

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