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Optimizing stations location for urban noise continuous intelligent monitoring

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ABSTRACT

In most of urban noise monitoring systems, the optimization of number and locations of autonomous monitoring stations is a Non-deterministic Polynomial Complete (NPC) problem. It is also important for the implementation of intelligent measurement networks. This paper investigates an optimization method to achieve minimum stations for urban noise intelligent monitoring. First a mathematical model for monitoring stations selection has been developed. Next, a novel hybrid Immune PSO K-means (IPKM) clustering algorithm is proposed to solve the mathematical model. The IPKM algorithm can overcome the shortcomings (e.g. slow convergence speed) of the Particle Swarm Optimization (PSO) algorithm, and help K-means clustering algorithm escaping from local optima. Finally, the methodology has been applied to QingDao urban noise intelligent monitoring networks. For comparison, the K-means algorithm and IPKM algorithm are applied to the noise grid survey datasets of 1998–2014 years. The final optimized results illustrate the proposed method could perform relevant monitoring tasks with fewer monitoring stations. In addition, the importance of the proposed method is that it would be applicable for noise monitoring and noise control management problems.

1. Introduction

Noise is among the most pervasive pollutants today [1,2]. According to statistical data, resident petition to reduce noise pollution is more common than those for air pollution [3]. The monitoring of noise effect is crucial to evaluate noise reduction measures for existing noise sources [4,5]. Measured data that comes from the noise monitoring system is useful for noise analysis and reduction [6,7]. In China, the environmental monitoring institutions should implement general noise grid survey at least once a year [8]. However, noise monitoring is manual monitoring which is arduous. Moreover, it is carried out only once in ten minutes every year. This kind of “short time measurements” cannot meet the new requirements and constraints of environmental noise management issues in complex urban context [9]. Long-term environmental monitoring [10] of noise levels can be done using autonomous measurement networks [11] as shown in Fig. 1. Intelligent measurement makes possible the advanced analysis of acoustic environment. Compared with manual monitoring, the noise automatic monitoring can really reflect the urban noise environment quality. Due to the high purchase of noise monitoring device, the station number in intelligent measurement is severely limited [12]. At present, urban automatic noise monitoring system is being at the start stage in China. Then it is essential to identify how many measuring localization points are really required. At the same time, it is vital to find most appropriate locations for measurement stations to obtain adequate measurement results.

Based on the historical noise grid survey datasets, the upper problem can be interpreted as classification of measured data of the grid points. It is ascribed to Non-deterministic Polynomial Complete (NPC) problem that can be solved by clustering techniques [13]. K-means clustering algorithm is a widely adopted clustering technique, and aims to divide n data points into K non-overlapping clusters, in which each point pertain to the cluster with high degree of similarity [14–16]. However, the K-means algorithm has two defects related to initial value. One is the number of clusters K that is needed to be initialized, and the other is the initial random seed points [13,17]. It is a good candidate for extension to work with evolutionary algorithm. The Particle Swarm Optimization (PSO) algorithm belongs to the modern evolutionary algorithms, and has high convergence speed for initial stage of a global search [18,19]. Unfortunately, search speed reduces obviously around global optimum because of degeneration [20]. In order to slowdown the degeneration of PSO, immune technology can be introduced into PSO algorithm to construct an Immune

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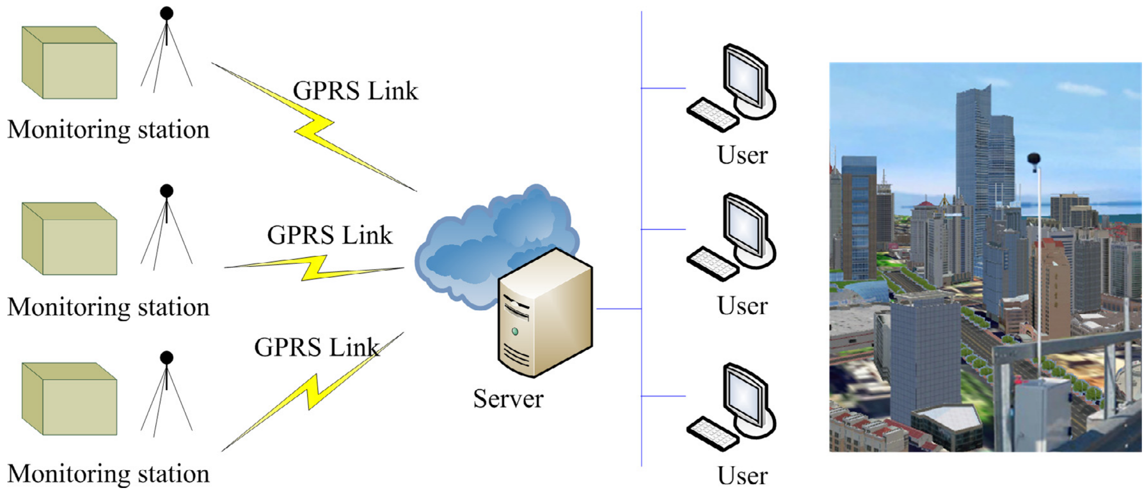

Fig. 1. Noise monitoring networks.

Technology PSO (ITPSO) algorithm [21]. At the same time, K-means algorithm can achieve faster convergence to optimum solution [22]. However, little research has been focused on optimizing urban noise monitoring stations with hybrid algorithm combining K-means and ITPSO algorithm.

The purpose of this paper is to propose an optimizing method for urban noise intelligent monitoring stations with noise grid survey datasets. The organization of this paper is as follows: Section 2 analyzes optimization problem of noise monitoring station thoroughly, describes the relevant definitions, builds the mathematical model of optimization problem, and designs algorithm for proposed model. In Section 3, the methodology is applied to an illustrative case. The results are discussed in Section 4. Section 5 is the conclusion of the paper.

2. Methodology for optimizing the noise monitoring stations

2.1. Research program

This study aims to identify the proper choice of intelligent measurement stations based on noise grid survey datasets. Traditional noise grid survey monitoring is relative subjective and random. For large monitoring area, if two grid survey points have the same value of noise indicators, it means that these two points have similar acoustic environmental features. Therefore, the number of monitoring stations can be reduced. The determination of the number and position of intelligent measurement nodes needs theoretical guidance, which includes mathematical model and quantitative analysis. Moreover, the method must guarantee monitoring the noise environmental features with the fewest number of monitoring stations. Also, the monitoring results should be consistent with the noise grid survey results. The overall research program is illustrated in Fig. 2.

(1) Determine research scenario. According to the change of noise sources when historical monitoring data was taken, the research scenarios are divided into two types. It is note that noise grid survey for influenced area must be implemented if there are major changes.
(2) Realize optimization process. Carry out noise grid survey data preprocessing combining with noise control zones, establish optimization model, and design algorithm for proposed model.
(3) Finally, output the optimization results and carry out spatial-temporal analysis.

2.2. Mathematical model

The purpose of mathematical model is to minimize the number of monitoring stations with historical grid monitoring data. Assuming that there are n noise survey points $\{L_1, L_2, \ldots, L_n\}$, each grid monitoring point L_i is a m-dimensional vector $L_i = \{L_{i1}, L_{i2}, \ldots, L_{im}\}$, every element L_{ik} represents a specific noise indicator, such as L_{Aeq}. Furthermore, the grid survey points are located in corresponding noise control zone. L_i^k can be defined as the ith noise survey point of control zone k, where $k = 0, 1, \ldots, l$. In the same way, each point is a m-dimensional vector $L_i^k = \{L_{i1}^k, L_{i2}^k, \ldots, L_{im}^k\}$, $i = 0, 1, \ldots, n_k$, n_k is the noise survey point number of acoustic control zone k. The total number of noise survey point is $\sum_{k=0}^{l} n_k = n$. Consequently, the optimization results of stations can be achieved by partition n noise grid points into a minimum of clusters. Furthermore, in each cluster the noise indicators values of grid point have a high degree similarity, and are very dissimilar to data in other clusters.

In order to describe the mathematical modeling of optimization problem, variables u_j, u_{jopt}, σ_j, σ_{jopt}, u_{kj}, u_{kjopt}, σ_{kj}, σ_{kjopt} are adopted. u_j and u_{jopt} are the jth comprehensive evaluation indicator average value of monitoring points before and after optimization, computational formula is Eq. (1). σ_j and σ_{jopt} are the jth noise indicator standard deviation of monitoring stations before and after optimization, computational formula is Eq. (2). u_{kj} and u_{kjopt} are the jth noise indicator average value of acoustic control zone class k before and after optimization, computational formula is Eq. (3). σ_{kj}, σ_{kjopt} are the jth noise indicator standard deviation of control zone class k before and after optimization, computational formula is Eq. (4).

$$u_j = \sum_{k=1}^{l}\sum_{i=1}^{n_k} L_{ij}^k \Big/ n, \quad u_{jopt} = \sum_{k=1}^{l}\sum_{i=1}^{n_k} L_{ij}^k x_i^k \Big/ \sum_{k=1}^{l}\sum_{i=1}^{n_k} x_i^k \tag{1}$$

$$\sigma_j = \sqrt{\sum_{k=1}^{l}\sum_{i=1}^{n_k} \left(L_{ij}^k - u_j\right)^2 \Big/ n},$$

$$\sigma_{jopt} = \sqrt{\sum_{k=1}^{l}\sum_{i=1}^{n_k} x_i^k \left(L_{ij}^k - u_j\right)^2 \Big/ \sum_{k=1}^{l}\sum_{i=1}^{n_k} x_i^k} \tag{2}$$