Distributed VOCs Gas Monitoring System in Large and Medium Cities

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Abstract. VOCs are the most important task of urban air pollution control at present, and its wide variety and emission range are important factors to produce haze. In this paper, a ladder distributed node network detection platform based on high performance electrochemical nanoarray gas detection chip and NB-IoT low power consumption is proposed. It is beneficial for environmental protection department to supervise VOCs, and reduce energy consumption while ensuring accuracy.

1. Introduction

Along with the continuous development of industrial urbanization, the consumption of energy is increasing, the air pollution in large and medium-sized cities is becoming more and more severe, which threatens the health of the people and is not conducive to the sustainable development of society. The treatment of volatile organic compounds (VOCs) is an important task of air pollution prevention and control.[1] However, because of the wide variety of VOCs, chemical and physical properties, and the wide range of emission sources, its monitoring is very challenging. Based on the ladder distributed arrangement of the number of nodes according to the distance between the source and the emission source, the electrochemical impedance sensor is used to detect the gas and combine the high precision denoising algorithm to remove the noise. The gas monitoring range of each sensor is realized with the same accuracy as other detection instruments. Through comparing the range of sensor resistance increase or decrease, the content of VOCs compounds in the detected gas can be accurately judged and combined with the Internet of things technology, the information collection, information transmission and state monitoring of each VOCs monitoring unit are carried out based on NB-IoT technology. The gas monitoring range of large chemical industry areas and cities is realized, and the real-time distribution model of regional gas is constructed according to the data of each monitoring node, which can locate the location of gas emission sources in the monitoring area. Finally, the fixed emission source information of VOCs emission exceeding the standard is feedback to the local environmental protection department in real time, and the pollution alarm is realized.

2. Overall system design

This project team designed a VOCs gas monitoring device, using electrochemical gas detection chip to achieve high precision detection for VOCs gas. Using distributed monitoring based on Internet of things, the VOCs emissions of chemical plant and city can be monitored in real time, and the VOCs gas distribution map can be constructed by establishing a model to determine the fixed emission source information. And the real-time data and emission source information can be fed back to the
environmental protection department in real time, which can clean up and rectify the key sewage units in time, and realize the effect of VOCs emission reduction in the monitoring area. The working structure of the low power region distributed VOCs monitoring system designed by the project team is as follows: when the factory emits exhaust gas into the atmosphere, the gas monitoring module distributed in the city will monitor the concentration of various types of VOCs in the atmosphere in real time. Users access the cloud platform and display it on the device terminal. Figure 1 shows the structure diagram of distributed VOCs gas monitoring and warning system.

![Structure Diagram of VOCs Gas Monitoring and Warning System](image)

3. Design of gas monitoring units

Through the investigation of VOCs online monitoring system in the market, aiming at the shortcomings of the existing VOCs monitoring products, such as single type, low precision, high price and large energy consumption, the project team proposes a VOCs monitoring unit with high precision, low energy consumption, small volume and many kinds of VOCs detection.

3.1. High performance electrochemical gas detection chip

In this paper, electrochemical impedance sensor is used for gas detection. It is a kind of sensor with simple structure, stable and low energy consumption, which is suitable for the detection of all kinds of gases. By the change of sensor resistance and capacitance, the composition content of the gas can be detected and analysed. Various nano sensor arrays can be prepared on conductive substrates by nano lithography, SU-8 template technology, and contact printing technology and so on. At the applied voltage, the specific VOC gas will stably adsorb between the semiconductor surface and the grain interface, and the oxidizing gas will obtain free electrons and form negative ions. The negative charge density of the surface and grain interface of sensitive material increases, the conductivity of the material decreases and the resistance increases. Accordingly, the type, content and concentration of VOCs compounds in the gas can be accurately determined by comparing the increase or decrease of resistance and the amplitude of increase or decrease.

3.2. Design of High Precision Voltage and Current Denoise Detection Algorithm

This design aims at the problem of noise in the voltage and current read from the electrochemical detection chip, so a high precision denoising detection algorithm is needed to remove noise. By
constructing the improved threshold function, the advantage of empirical mode decomposition and wavelet transform is used to optimize the harmonic signal accurately to overcome the discontinuity and deviation in the wavelet threshold function and to optimize the precision operation.

Improved threshold function:

\[
\begin{aligned}
&\begin{cases}
  w_{j,k}^* - \alpha \cdot \text{sgn}(w_{j,k})|w_{j,k}| > \lambda \\
  \alpha \cdot \text{sgn}(w_{j,k})\left(\frac{|w_{j,k}|^{p+1}}{1+|w_{j,k}|^p}\right), |w_{j,k}| \leq \lambda
\end{cases}
\end{aligned}
\]

By adjusting the threshold function, the soft and hard threshold function can be converted flexibly, and the smooth transition of the optimized signal can be better realized by constantly changing the value of the parameters. If the number of decomposition layers is increased by a fixed threshold, there is some irrationality, so the original threshold is adjusted to the number of decomposition layers.

\[
\lambda = \sigma \sqrt{2 \log(N) / (1 + \frac{1}{j})}
\]

The improved threshold function has a good smooth transition and the signal waveform is stable. Therefore, in this paper, the voltage and current signals are optimized by the partial hard threshold function at high frequency to filter out most of the noise, and the low frequency coefficients are optimized by the soft threshold function to realize the preservation of the effective signals.\(^3\) The test results based on the improved algorithm are shown in figure 2:

![Image of the original signal, the signal denoising, and the reconstructed signal](image)

Fig. 2. Noise Testing after Improved Algorithm.
4. Design of Internet of Things Distributed Detection Platform

4.1. Grid placement method for gradient distribution

On the basis of the importance of the area, the pollution of air pollutants and the level of industrial development, the grid distribution method is used to grid the area and set up the monitoring points at the intersection of the grid. It can not only ensure the accuracy and effectiveness of the detection, but also facilitate the scientific decision of pollutant control."[4] A dense grid arrangement is used in the area where the key units of VOCs emission are concentrated, such as the chemical plant area. For the main urban area (mainly including commercial and residential areas), sparse grid points are used. Taking some urban areas of Wuhan as an example VOCs the area of Wuhan Economic Development Zone (Hannon Industrial Park) is about 34.79 square kilometres. According to 0.5 km × 0.5 km grid layout monitoring nodes, the number of nodes is about 139. Wuhan central urban area 863 square kilometres, according to 1.5 km grid layout monitoring nodes, the number of nodes is about 384. The suburb of Wuhan (excluding Xinzhou District and Huangpi District) has an area of 3844 square kilometres. The monitoring nodes are arranged according to 2 km × 2 km grid, and the number of nodes needed is about 961. The total number of nodes is about 1484.

4.2. NB-IoT-based distributed low-power monitoring

The narrowband Internet of things (NB-IoT) has the advantage of ultra-low power consumption and is suitable for large-scale coverage. At the same time, the large-scale real-time data transmission supported by the NB-IoT can send a large number of VOCs monitoring unit detection data back to the cloud platform in time. This system mainly carries on the information collection, the information transmission and the status monitoring to each VOCs monitoring unit based on the NB-IoT technology."[5] The NB-IoT network structure diagram is shown in figure 3. Its Internet of things composition mainly includes VOCs monitoring unit, NB-IoT base station, server and application layer.

![NB-IoT Network structure diagram](image)

The Internet of things communication unit BC95 connected with the VOCs detection chip to VOCs the monitoring unit as the data source. Monitoring unit periodically collects data and uploads it to the cloud through NB-IoT technology.

5. Design of Gas Diffusion Concentration and Location

The isoline reflects the visualization of the data, and the mathematical interpolation method is used to realize the numerical dispersion and gridding of the monitoring data, and the points of the same value are drawn into intuitive image information."[6] Kriging interpolation is used to estimate the VOCs concentration near the monitoring coordinates.

\[
\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i)
\]
$Z(s_i)$ is the measurement value at the $i$ position and $\lambda_i$ is the unknown weight prediction position at the $i$ position. $N$ is the number of measured values. The coordinates and concentration values of each monitoring node of the Surfer are imported, and the gas diffusion contours are drawn by Kriging interpolation method.

According to the gas diffusion isoline, the distribution of VOCs gas in the city can be observed intuitively. DE search algorithm is used to determine the location of emission sources in regions with high VOCs concentration. At the same time, the Elman neural network is used to optimize the Elman neural network by genetic algorithm. The prediction model of VOCs concentration in the atmospheric environment is constructed.

According to the data query port provided, the system can obtain the historical data of a node in the selected area, node and time period. It can also display the VOCs gas concentration data in the way of continuous change curve, and can display the gas concentration in the whole monitored urban area in real time, which is convenient for the monitor to analyze the possibility of gas occurrence in the area.

6. Conclusion
This paper designs a new VOCs monitoring scheme, which strengthens the supervision ability of environmental protection department to VOCs emission, prevents the factory from exceeding the standard discharge VOCs, and improves the air quality and national health. At the same time, the monitoring equipment used in the system is low power equipment. Compared with the existing monitoring means, the energy consumption is reduced while ensuring the accuracy. It not only promotes the intelligence and information of air quality monitoring, but also helps the supervision and control of air pollution. It not only promotes intelligent and informationized air quality monitoring, which is conducive to the supervision and control of air pollution, but also conforms to the concept of "green energy saving" environmental governance.

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