Research on Infrared Carbon Monoxide Monitoring System Based on Least Squares Support Vector Machine

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Abstract

Carbon Monoxide (CO) is a kind of poisonous and explosive gas which does harm to people and safety production. A infrared Carbon Monoxide monitoring system based on Least Squares Support Vector Machine is illustrated. Detected principle of infrared Carbon Monoxide is introduced. The mathematical model of infrared Carbon Monoxide based on Least Squares Support Vector Machine was built to dispel the influence of environment such as temperature and humidity. The hardware of the monitoring system is also introduced. The experimental results show that the infrared Carbon Monoxide monitoring system works well with a high precision and satisfies the demands of people.

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Keywords: Infrared; Carbon Monoxide sensor; Model; Least Squares Support Vector Machine; Monitoring system

1. Introduction

Carbon monoxide (CO) is a kind of colorless and odorless gas produced from incomplete oxidation of carbon, and carbon monoxide is also poisonous and explosive which does enormously harm to human health and safety production. Carbon monoxide sensors are widely used in different aspects such as environmental protection, agricultural and industrial production, daily life and military field[1]. According to different detection principle, there are infrared carbon monoxide sensor, carrier catalytic carbon monoxide sensor, electrochemical sensor, solid state carbon monoxide sensor, and so on. The technique of
infrared detection has already become the most frequently used detection method, but the output of the infrared CO sensor is easily influenced by environment aspects such as temperature and humidity[2]. The Support Vector algorithm is a nonlinear generalization of the generalized Portrait algorithm Support Vector Machine (SVM) is a novel machine learning method which is powerful for the problem characterized by small sample, high dimension, non-linearity, and local minima[3]. In order to enhance the precision of carbon monoxide detection, a infrared Carbon Monoxide monitoring system based on Least Squares Support Vector Machine is designed.

2. Infrared detection principle

We can determine which gas is present and in what quantity by analyzing its unique optical absorption spectrum because each pollutant gas has characteristic optical absorption spectrum in the 2-14 $\mu$m region of the electromagnetic radiation spectrum, and carbon monoxide exhibits very strong absorption in 4.65 $\mu$m of infrared spectrum. The amount of light absorbed in any unit volume is proportional to the intensity of incident light times the absorption coefficient when a beam of light passes through an absorbing medium, then the intensity of an incident beam drops exponentially as it passes through the absorber. This relationship can be expressed as follow:

$$P(t) = P_0(t) \exp\{-k(\lambda)CL\}$$ (1)

Where $P(t)$ is the intensities of transmission light, $P_0(t)$ is the intensities of incident light. $k(\lambda)$ is the gas absorption coefficient, it is the function of the wavelength of radiation. $C$ is the concentration of carbon monoxide. $L$ is absorption length.

From the (1), the concentration of carbon monoxide can be measured by the intensity of incident light and transmission light as follow:

$$C = \frac{1}{k(\lambda)L}\{\ln[P(t)] - \ln[P_0(t)]\}$$ (2)

$k(\lambda)$ is variable and it affect light intensity of absorption directly when the temperature and the pressure changing. Infrared absorption model is usually adopted to detect the concentration of carbon monoxide[4-6]. The Elsasser model, Statistic model, Stochastic model and Quasi Stochastic model are present commonly used infrared absorption model. The error of detecting concentration of micro-carbon monoxide will be greater because of the assumed condition in each absorption model. It is very difficult for the precision to meet the demands of detecting.

3. Set up the mathematics model of infrared carbon monoxide sensor based on Least Squares Support Vector Machine

3.1. Necessity of set up the mathematics model of carbon monoxide sensor

Scattering attenuation of infrared radiation is ignored when the absorption model is set up. Parameter $K$ is affected by such as the size of sensor component, working temperature, radiance, and so on. The output of the carbon monoxide sensor is also affected by the factors such as the variation of the infrared source power, the change of sensitivity of the detector and the electromagnetic interference. It is different to compensation the error of the output of the carbon monoxide sensor through hardware method because some factors that influence the detecting error are stochastic. It is necessary to set up the mathematics model of infrared carbon monoxide to enhance the measure precision.
Support Vector Machine is powerful for the problem characterized by small sample, high dimension, nonlinearity, and local minima, which is a novel machine learning method[3]. The Support Vector algorithm is a nonlinear generalization of the Generalized Portrait algorithm, it is firmly grounded in the framework of statistical learning theory or VC theory, and it has no the problem of excessive learning, not enough learning and local minimum point existed in the algorithm of radial basic function’s neural network. Kernel is the hard core of support vector machine technology, which helps SVM replacing the local minimum value and the dimension disaster, keeping the sparseness of solution. By replacing the inner product with an appropriately chosen kernel function, one can implicitly perform a non-linear mapping to a high dimensional feature space without increasing the number of tunable parameters, provided the kernel computes the inner product of the vectors corresponding to the two inputs. The main idea of support vector machine is that by projecting the data into a high dimensional feature space to construct optimal hyperplanes in order to carry out the learning and forecasting of the primary space utilizing kernels by replacing inner product and the dimensional disaster, therefore the extension ability of support vector machine is good. The complexity of the algorithm has nothing with the dimension of data, but the number of vectors[7-9]. Support Vector Machine can be applied to regression problems by the introduction of an alternative loss function. So the Least Squares Support Vector Machine is adopted to set up mathematic model of infrared carbon monoxide sensor so as to improve the measurement precision of the infrared carbon monoxide sensor.

3.2. Set up the mathematics model of carbon monoxide sensor based on Least Squares Support Vector Machine

Consider a given training set of data \((x_1, y_1), (x_2, y_2), \ldots, (x_l, y_l)\), with input \(x \in \mathbb{R}^N\) and output \(y \in \mathbb{R}\). The goal is to find a function \(f(x)\) that from the actually obtained targets \(y_i\) for all the training data[10]. In feature space, the regression function \(f(x)\) of Least Squares Support Vector Machine takes the form:

\[
f(x) = w \cdot \phi(x) + d
\] (3)

Where \(w\) is weight vector, \(\phi(x)\) is the nonlinear map from the input space to the feature space. \(d\) is the deviation. The problem of optimal regression function can be changed to the problem of optimal function as follow:

\[
\Phi(w, \xi) = \frac{1}{2} \|w\|^2 + \frac{C}{2} \sum_{i=1}^{l} \xi_i^2
\] (4)

Where \(\xi_i\) is the slack variables, it represents the lower and upper constraints on the outputs of the system. \(C\) is the regularization parameter, which controls the penalty degree to the sample. The problem of optimal function can be given by the minimum of the functional [11, 12]:

\[
\min \left\{ \frac{1}{2} \|w\|^2 + \frac{C}{2} \sum_{i=1}^{l} \xi_i^2 \right\}, \text{ Subject to } y_i - (w \cdot \phi(x) + d) = \xi_i, i = 1, \ldots, l
\] (5)

Lagrange function can be defined as follow:

\[
L(w, d, \xi, \alpha) = \frac{1}{2} \|w\|^2 + \frac{C}{2} \sum_{i=1}^{l} \xi_i^2 - \sum_{i=1}^{l} \alpha_i (w \cdot \phi(x) + d + \xi_i - y_i)
\] (6)

Where Lagrange multiplies \(\alpha, \alpha^*\) are utilized. According to the KKT optimization conditions,
\[ \frac{\partial L}{\partial w} = 0 \Rightarrow w = \sum_{i=1}^{l} \alpha_i \phi(x_i), \frac{\partial L}{\partial \xi} = 0 \Rightarrow \alpha_i = C \xi_i \]
\[ \frac{\partial L}{\partial d} = 0, \sum_{i=1}^{l} \alpha_i = 0, \frac{\partial L}{\partial \alpha} = 0, y_i = w \cdot \phi(x) + d + \xi_i \]

The function can be obtained as follow:
\[ W(\alpha, \alpha^*) = \sum_{i=1}^{l} \alpha_i y_i - \frac{1}{2} \sum_{i=1}^{l} \sum_{j=1}^{l} \alpha_i \alpha_j \langle \phi(x_i) \cdot \phi(x_j) \rangle + \frac{\lambda_{ij}}{C} \]

Where \( \lambda_{ij} = 1, i = j \), \( \lambda_{ij} = 0, i \neq j \), Kernel \( K(x_i, x_j) = \langle \phi(x_i) \cdot \phi(x_j) \rangle \). Gaussian RBF kernels is adopted in this paper. The problem of optimal function can be given by the maximum of the function as follow:
\[ \max \sum_{i=1}^{l} \alpha_i y_i - \frac{1}{2} \sum_{i=1}^{l} \sum_{j=1}^{l} \alpha_i \alpha_j \langle \phi(x_i) \cdot \phi(x_j) \rangle + \frac{\lambda_{ij}}{C} , \text{Subject to } \sum_{i=1}^{l} \alpha_i = 0 \]

\( \overline{w} \) and \( \overline{d} \) can be solved as follow:
\[ \overline{w} = \sum_{i=1}^{l} \alpha_i^* \phi(x_i), \overline{d} = y_i - \frac{\alpha_i^*}{C} - \sum_{j=1}^{l} \alpha_j^* K(x_j, x_i) \]

The regression function is given by as follow:
\[ f(x) = \sum_{i=1}^{l} \alpha_i^* K(x_i, x) + \overline{d} \]

3.3. The implementation of mathematics model of carbon monoxide sensor based on Least Squares Support Vector Machine

The implementation of mathematics model based on Least Squares Support Vector Machine can be described as follow:
\[ \min \frac{1}{2} B^T AB + G^T B \]

Where
\[ A = \begin{bmatrix} XX^T & -XX^T \\ -XX^T & XX^T \end{bmatrix}, D = \begin{bmatrix} \varepsilon + Y \\ \varepsilon - Y \end{bmatrix}, B = \begin{bmatrix} \alpha \\ \alpha^* \end{bmatrix} \]
\[ X = [x_1, \ldots, x_l]^T, Y = [y_1, \ldots, y_l]^T \]

The value of \( B \) is subjected to:
\[ B \cdot (1, \ldots, 1, -1, \ldots, -1) = 0, \alpha_i, \alpha_i^* \geq 0, i = 1, \ldots, l \]

4. The system hardware design

A new style of infrared carbon monoxide monitoring system based on embed Linux real time system is designed, the structure of hardware system is shown as Figure 1. Embed 32 bits SAMSUNG S3C2410A based on ARM920T core worked as CPU of the system, which has the character of high
capability, low power consumption, and abundance exterior device. AD8541AKSZ is adapted as amplifier device. The signal of concentration of carbon monoxide among of multi-component gas is transformed by infrared carbon monoxide sensor into a voltage signal, which is as the input signal of CPU S3C2410A after the amplifier and filter circuit. The signals of meteorological conditions temperature and humidity are also sent to CPU. The system restart, data collection, LCD display with LTS350Q-PD1 at the mode of real time and storage the concentration of carbon monoxide, human-computer interaction by means of touch screen with Fdc6321, uart communication, and alarm at the mode of sound and light, and so on, functions are carried out by DMA. The hardware system mainly consist of S3C2410A, amplifier and filter circuit, LCD, human-computer interaction, alarm interface, communication interface, and so on.

Figure 1 Schematic diagram for the structure of infrared carbon monoxide monitoring system

5. Experiment results

The prototype is tested at different condition. The temperature were 5°C, 10°C, 20°C, 25°C, 30°C, 40°C, humidity were 50%, 60%, 70%, 80%, 95%, and standard carbon monoxide concentration are 0.6%, 1.5% and 3.0% when experiment, the experimental data is shown as table 1. The maximum relative error is 8.75%, and the influence of temperature and humidity is greatly reduced. The experiment results indicate the satisfied capability of the new instrument, that is anti-jamming, high stability and precision, low power consumption, which meet the demand of people.

Table 1 The experiment result of performance tested of the infrared carbon monoxide monitoring system based on Least Squares Support Vector Machine

| T    | H  | Standard concentration | Testing Value | Relative error | T  | H  | Standard concentration | Testing value | Relative error |
|------|----|------------------------|---------------|----------------|----|----|------------------------|---------------|----------------|
| 5°C  | 50%| 0.6%                   | 0.6494%       | 0.0823         | 25°C| 80%| 0.6%                   | 0.5897%       | 0.0172         |
|      |    | 1.5%                   | 1.4306%       | 0.0463         |    |    | 1.5%                   | 1.4671%       | 0.0219         |
|      |    | 3.0%                   | 3.1994%       | 0.0665         |    |    | 3.0%                   | 2.9050%       | 0.0317         |
| 10°C | 60%| 0.6%                   | 0.5753%       | 0.0412         | 25°C| 90%| 0.6%                   | 0.5860%       | 0.0233         |
|      |    | 1.5%                   | 1.3687%       | 0.0875         |    |    | 1.5%                   | 1.5381%       | 0.0254         |
|      |    | 3.0%                   | 2.8257%       | 0.0581         |    |    | 3.0%                   | 2.9067%       | 0.0311         |
| 10°C | 70%| 0.6%                   | 0.6098%       | 0.0163         | 30°C| 90%| 0.6%                   | 0.5519%       | 0.0802         |
|      |    | 1.5%                   | 1.5450%       | 0.0300         |    |    | 1.5%                   | 1.4748%       | 0.0168         |
|      |    | 3.0%                   | 3.2548%       | 0.0849         |    |    | 3.0%                   | 2.8976%       | 0.0341         |
| 20°C | 70%| 0.6%                   | 0.6494%       | 0.0823         | 40°C| 95%| 0.6%                   | 0.6241%       | 0.0402         |
|      |    | 1.5%                   | 1.3712%       | 0.0859         |    |    | 1.5%                   | 1.4344%       | 0.0437         |
|      |    | 3.0%                   | 3.1193%       | 0.0398         |    |    | 3.0%                   | 3.2081%       | 0.0694         |
6. conclusions

The infrared carbon monoxide monitoring system based on Least Squares Support Vector Machines which is powerful for the problem characterized by small sample, non-linearity, high dimension, and local minima is applied in the paper. Least Squares Support Vector Machine is adopted to set up mathematics model of infrared carbon monoxide sensor so as to improve the measurement precision of the infrared carbon monoxide sensor. The experiment results show the influence of temperature and humidity is greatly reduced by using of the infrared carbon monoxide sensor mathematics model based on Least Squares Support Vector Machine. This method also can be used to detecting other gas such as carbon dioxide, methane, etc. The infrared carbon monoxide monitoring system based on Least Squares Support Vector Machine has promising future.

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