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Application of Wireless Sensor Based on Sound Localization in Safety Valve Condition Monitoring of Chemical Plant

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In recent years, accidents occurred in the chemical plant are linked to the failure of the safety valve or the excessive mechanical stress, and the reasons are mainly related to the safety of the safety valve, piping, support selection and the stress overload of the safety valve and the attached pipelines. The status of the safety valve cannot be effectively monitored, so that blind spots exist in the industrial production process, which has taken great operational risk. Voice recognition is an important subject of pattern recognition, and is the most important part of the security monitoring system. In this paper, the state monitoring of safety valve in industrial production is studied with the latest acoustic identification localization algorithm as well as the advanced wireless sensor network. Firstly, the working principle and the pressure mode of the safety valve are studied. Secondly, the key algorithm is analyzed for the audio frequency detection. As for the problems faced in industrial production, this paper proposes a new wireless sensor network application model that is based on the new audio detection algorithm. When this technology is applied, the problem that the state of the safety valve cannot be monitored can be effectively solved. Finally, on the basis of the above research, this paper designs and implements a set of safety valve take-off positioning system which is based on audio sensor, and some relevant experiments are designed to verify it. It has the characteristics of accurate location, small disturbance, low cost and little robustness, which is a successful exploration and attempt of industrial production by using artificial intelligence and sensor technology.

1. Introduction

Safety valve is a kind of important safety protection equipment in industry, which involves many aspects of industrial production, and is very important basic equipment. The safety valve is automatic, which adopts the force of the medium itself to discharge a nominal amount of fluid without using any external power, so as to prevent the pressure from exceeding a predetermined safety value. When the pressure returns to normal, the valve will be closed again, and prevent the media from continuing to run. Many standards and regulations have been formulated for the design, manufacture, use and management of safety valves at home and abroad. In 1980s and 90s, Professor Sallet of the Maryland University conducts many creative experiments about the safety valve (Sallet et al., 1981; Sallet, 1984), and also gets a series of important results. Narabayashi and Nagashaka do rupture tests on the safety valve. In their study, the single-phase super-cooled water and two-phase mixture of water and steam are used as mediators to evaluate the characteristics of the safety valve (Narabashi et al., 1986). Francis and Betts (1997 and 1998) study the pressure distribution under the disc of a safety valve when a compressible flow occurs in a commercial safety valve, and they also determine the critical pressure ratio. In 1990s, computer technology has got a rapid development, and many scholars introduce the numerical calculation technology into the research of safety valve. Wu and Wang adopt the method of computational fluid mechanics (CFD) to analyze 3D complex flow of the safety valve in the opening process (Wu and Wang, 1997). Their research results show that in the process of pressure release, the opening port of valve forms a vortex, which is consistent with the position of the valve body erosion in the actual conditions. Ahuja et al. use the low temperature fluid as the medium to simulate the cavitation appearing in the working process of high pressure valve port (Ahuja et al., 2007). The gas liquid compressible multiphase flow model based on the compressible gas-liquid multiphase flow model, they simulate the formation of cavitation and the vibration vocal phenomenon of the gas-liquid two-phase flow.

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The passive acoustic localization is realized through the acoustic sensor array. It firstly acquires the signal information of the sound source to be measured through each node in the sensor network, and then uses the signal processing module in the positioning system to analyze and process the acquired sound signals. Finally in the positioning space defined by the positioning system, the plane two-dimensional coordinates or three-dimensional coordinates of the single or multiple sound sources are determined, that is, the estimated position of the sound source signals to be measured is obtained. Like many techniques, acoustic source localization is firstly applied to military fields. As early as the First World War, people begin to use the sound of artillery fire to determine the position of enemy guns (Jin and Yang, 2007).

As a new generation of wireless network communication technology, wireless sensor networks have a broad application prospect, whose development and application will bring a far-reaching impact to all areas of human life and production. While, the use of advanced wireless sensor systems can effectively support the development of industrial modernization. This paper designs and implements a set of safety valve take-off positioning system, which is based on audio sensor. In addition, this paper also designs some relevant experiments to verify it. The system has the characteristics of accurate location, small disturbance, low cost and little robustness, which is a successful exploration and attempt of industrial production by using artificial intelligence and sensor technology.

2. Safety valve technology

The safety valve is the accessories for overpressure protection in the equipment, installations and piping, which is also the last passive safety measures in the pressure system to prevent the pressure of the medium in the equipment, pipeline from exceeding the certain value. When the working pressure of the medium in the pressure system exceeds the setting pressure of the safety valve, the safety valve will automatically open so as to discharge the excess media. When the system pressure returned to normal, the safety valve will automatically shut down, so that the device can prevent the flow of the media from continuing to flow, and results in excessive waste of media in the system.

Full valve has a variety of types, and different types of safety valve have different structure and characteristics. At present, the spring (-loaded) pressure relief valve is the most commonly used valve, which accounts for more than 80%. A spring (-loaded) pressure relief valve is a safety valve that uses the force produced by spring compression to balance the pressure acting on the disc and seal the contact between the disc and the valve seat. It is mainly made up of the valve seat, valve body, regulating nut, valve, adjusting ring, guide sleeve, valve cover, spring seat, spring, stem, adjusting screw, lock nut, bonnet and other components.

When the pressure of the medium in the equipment is less than the setting pressure of the safety valve, the force acting on the valve is smaller than the force on which the spring is loaded. The difference forms the sealing force between the valve disc and the valve seat, and then the safety valve is in a closed state, so the media cannot be ruled out. When the pressure of the medium in the equipment is equal to the setting pressure of the safety valve, the force acting on the valve on the valve is equal to the force acting on the valve by the spring. Then the force between the valve disc and the valve seat is equal to zero. When the pressure of the medium in the equipment is slightly greater than the set pressure of safety valve, the safety valve will open. At this time, due to the throttling effect of the recoil disc and the adjusting ring, the interior of the equipment will act on a larger area. When the dielectric force of the medium is much higher than the force of spring loading on the valve, the valve will reach the full open state. When the medium pressure in the equipment is smaller than the set pressure of safety valve and simultaneously the medium acting on the valve flap is less than the force that the spring loads on the valve flap, flap valve will come back to the closed state. At the same time, the media will stop the discharge, and the equipment continues to operate normally under specified operating pressure. Therefore, the safety valve achieves its own opening or closing, in order to prevent equipment overpressure through balancing the force that the medium acts on the disc and the force that the spring loads on the disc.

Pilot safety valve, is also known as the pulse type safety valve. This structure connects the two valves in series, and uses the pulse of the auxiliary valve to make the main valve act. It has the characteristics of high sensitivity, good sealing performance. However, for the full cost is relatively expensive, it is mainly applied in the large diameter, large displacement and high pressure environment.

3. Sound location system

The key to the target location of the acoustic positioning system is to determine the location of the target through using the sound generated by the target sound source. The basic principle of the localization is as follows. Firstly, the array with a certain geometry is set up in the space as the acoustic source to locate the base station. It aims to receive the acoustic information generated by sound sources. Then the received

acoustic information will be detected or calculated to get the time-delay quality of the detected signal in each base locating station so as to determine the direction and accurate distance of the specific goals.
The auditory localization mechanism of human ears, especially the binaural effect of hearing, provides a good idea for the research of sound localization technology. With the aid of some acoustic source localization algorithms, people can measure the position of sound source by microphone array, and the range and accuracy of localization are better than that of human auditory system. The theoretical basis of sound localization system is the analysis and design of algorithms, because the algorithm is the key step to solve the problem, and plays an important role in the system. Experience shows that with the increase of time and technology, the weakness of specific algorithm in-depth technical is not a specific technology or the corresponding technology, but the fact that the nature of this particular algorithm is the technique of regression. Therefore, the importance of the algorithm can be imagined. According to the system requirements, the algorithms used are divided into two kinds. One is the acoustic feature recognition algorithm, and the other is the sound localization algorithm.
The location algorithm is to locate the source of sound by using sound collector array to get the change of sound characteristics and the relationship of time. The commonly used localization algorithm is TOA (Time of arrival), which relies on the arrival time. It has very strong requirements for the time and also requires the system must be synchronized, so that positioning results can make sense. RSSI (Received Signal Strength Indicator) hasn't strict requirements for time. However, the signal transmission is easily affected by environment, so it has very high requirements on the external environment. TDOA (Time difference of Arrival) satisfies the requirements of time synchronization in a certain extent, and it is also slightly affected by the external environment.
TOA positioning method calculates the distance from the base station to the target of the source, according to the propagation velocity of sound and the propagation time of acoustic source signal. Then it uses the assumed nominal position to calculate the estimated position of the sound source.
Another method of locating the location of a sound source is the RSSI localization algorithm, which is based on the transmission and reception of electromagnetic waves. That is, when the transmitter signal is known, the distance between two points is calculated by analyzing the loss in the propagation process between the intensity of the signal received by the receiving node and the intensity of the signal at the sending end. From this, we can see that the wireless transmission signal will gradually attenuate with the increasing of distance attenuation.
Acoustic source localization method based on TDOA arrival time-delay is the most widely used method of localization. TDOA firstly estimates the relative time-delay that the sound signals of the target sound source reach each node in the acoustic sensor array. Secondly, it uses time delay estimation to calculate the distance difference that sound source reaches each sensor node. Finally it determines the target position of sound source to be measured through search or geometry algorithm. According to the different arrangement of microphone array and the fitting algorithm, the common positioning algorithms can be divided into some types like angle and distance positioning method, linear interpolation method and spherical interpolation method.
The distance angle method is a common method of using the four microphone to position. It generally uses four dimension T-shaped array or four dimension cross array. Here we will use the four dimension T-shaped array as an example. In the four dimension array shown in the figure, the microphone m_2 is located in the axis away, while the remaining three microphones are located on the axis of *x* and *y*, and the distance between them and m_2 is *a*. Besides, there is a sound source *S* in the space, whose coordinates are *(x, y, z)*, then the following parts can be obtained by geometric relationship.
First, the sound source is determined as the angle ψ to the axis *y* and the angle θ to the axis x. When the sound source signal reaches two microphones m_1 and m_3, which are located on a certain line, it can be represented as follows.

$$\|r_s - m_1\| - \|r_s - m_3\| = d_{13} \tag{1}$$

The polar coordinates (r, θ, φ) of the source position are converted into Cartesian coordinates and will be brought into the upper formula.

$$\frac{\cos^2\theta}{d_{13}^2} - \frac{\sin^2\theta}{|m_1 - m_3| d_{13}^2} = \frac{1}{4r^2} \tag{2}$$

In fact, the equation determines a hyperboloid, and in the far field, the right-hand side of the equation tends to be 0, so that it can be obtained.

$$\theta = \cos^{-1}\frac{d_{13}}{\|m_1 - m_3\|} = \cos^{-1}\frac{d_{13}}{2a} \quad (3)$$

At this time, the equation determines a cone which has angle θ with the axis x . In the case of far field sound source, the cone is a better approximation to the original hyperbolic surface. Similarly, we can also obtain the source location that has the angle ψ with the axis y .

$$\psi = \cos^{-1}\frac{d_{24}}{a} \quad (4)$$

At this point, the two cones intersect to obtain a unique line, so that if the distance between the sound source and the point of origin of the coordinate system is known, the location of the sound source can be uniquely determined. Through geometric space relations, it can be obtained as follows.

$$\sqrt{(x+a)^2 + y^2 + z^2} - \sqrt{x^2 + y^2 + z^2} = d_{12} \quad (5)$$

$$\sqrt{(x-a)^2 + y^2 + z^2} - \sqrt{x^2 + y^2 + z^2} = d_{32} \quad (6)$$

Setting $r = \sqrt{x^2 + y^2 + z^2}$, after the two formulas above are transposed and squared, the following can be obtained.

$$2xa + a^2 = d_{12}^2 + 2rd_{12} \quad (7)$$

$$-2xa + a^2 = d_{32}^2 + 2rd_{32} \quad (8)$$

After the merger, we can get the distance.

$$r = \frac{a^2 - \left(d_{12}^2 + d_{32}^2\right)/2}{d_{12} + d_{32}} \quad (9)$$

Distance and angle positioning method only needs four microphones to complete the location of sound source. In the process of locating, it only uses the simple delay operation between each microphone, which has a relatively small amount of data processing and easy to use. Sound feature recognition is to make a match between the acquired sound and the sound of the original sample to determine whether it is the same sound or similar sound. Traditional sound collection methods and processing patterns make it difficult to obtain specific sounds. In order to solve this problem, the related researchers conduct a lot of research work to obtain some effective voice recognition technology, such as the voice feature recognition technology based on the characteristics of wavelet feature, the voice specific recognition technology based on neural network, and the voice feature recognition technology based on the specific operational. Neural network theory is used to realize the characteristic recognition of sound. The process of voice recognition is divided into three parts. Firstly, the sound signal is preprocessed and the characteristic parameters of target sound are extracted. Secondly, the characteristic parameters of target voice are input, and neural network is trained. So the weights and thresholds of the neural network can be gained. Thirdly, the feature parameters of the sound to be measured are input to the neural network, and the trained neural network is used to discriminate the target.

4. System design

Traditional safety valve monitoring system is to fix the wireless sensor on the riser of the safety valve, and use the air flow sounds of standpipe to judge. This scheme requires a large number of safety valve monitoring sensors, which are expensive and inconvenient to maintain. The sound sensor can be positioned by the sound valve arranged in the production process device so that a sensor can be used to monitor a whole area. Safety valve take-off sound are obviously different from the process device production signals. In order to study the sound characteristics and identification system of safety valve take-off in factory production, we must establish a safety valve take-off sound library in a factory production environment. This paper collects 4 kinds of sound in the office environment (2 normal voice, and 2 abnormal voice). In this environment, 33000Hz is the sampling rate, 16bit is the digit capacity, and the files are saved in wav format. The normal production noise in the factory and the production noise when someone is talking are the normal voice, while the safety valve take-off sound and the return seat sound are abnormal sound. Each voice has 200 samples, and 800 audio samples in all, with the wav format as the file format. Figure 1 is the time domain waveform of safety valve take-off sound.

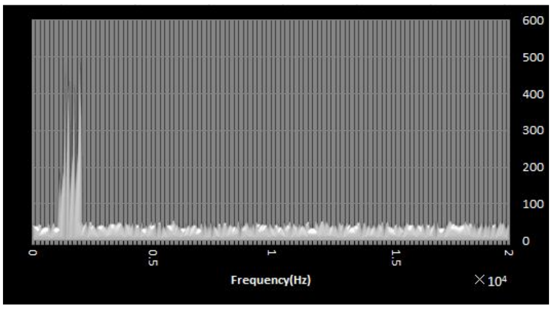

Figure 1: The Time Domain Waveform of Safety Valve Take-off Sound

In this paper, the neural network algorithm is used to recognize the take-off sound of the safety valve. In order to ensure good performance, the neural network algorithm is optimized. Gauss mutation and orthogonal hybridization are used in mutation operator and crossover operator of differential evolution algorithm, so that an interpolation of local search operator is presented. In addition, a differential evolution algorithm based on orthogonal and local search is proposed. In the case of predictor corrector method, a hybrid training algorithm is proposed by combining the improved differential evolution algorithm with the Levenberg-Marquardt (LM) algorithm, which optimizes the weights and threshold of feed forward neural network. The optimized algorithm has many advantages, such as fast convergence speed and excellent classification result.

As for the hierarchical topology control strategy of Wireless Sensor Networks, based on the analysis of the node energy consumption model, this paper presents an adaptive clustering algorithm which is based on the energy of node partition and effective distance. Because of introducing node partition mechanism, it has a balance between node communication distance and intra cluster load. At the same time, considering the energy and communication distance can save node energy in wireless sensor networks, so as to prolong the survival time effectively. Establishing safety valve take-off and return sound library can be effectively used for system design and analysis. An improved artificial neural network algorithm is introduced to classify the abnormal sounds, which improves the validity of the sound classification and its convergence speed. Finally, the network structure of the acoustic wireless sensor is optimized. What's more, the whole factory production area can be optimally covered while reducing the energy consumption.

5. Experiment and analysis

After completing the design of the sound source localization system of the whole safety valve, this part focuses on demonstrating and testing the system. The installation of the relief valve is in different planes due to the complexity of the process equipment in the production plant. In order to ensure better detection effect, the array of probes in this paper uses a solid array, which can effectively detect the action of the safety valve around the sensor. Acoustic source positioning system is different from other systems, and its hardware system is very simple, mainly including voice acquisition, encoder, transmission module, DSP microprocessor module. The processor uses ADI Blank fin 527 DSP as the control chip of the detection node. Detection nodes need to complete the preprocessing and preliminary positioning of the sound signal. Codec uses SSM 2602 chip, which is of high performance and low power audio acquisition. The transmission module uses CC2430 SDK development kit of TI, and each node carries a 51 microcontroller. In order to verify the actual performance of the system effectively, multiple experiments are designed in this paper. A probe node is placed at the origin of the coordinate axis, and a safety valve take-off sound generator, whose take-off pressure is 1.6MPa, is set at the place that has a 2m distance far from the origin. The sound source is going away from the probe node along a certain axis, and there will be a test for each additional 10cm. Figure 2 is the angular error of acoustic source location. The horizontal angle error of the sound source position is small at first, and it will begin to increase rapidly. The error will reach the maximum point, when the sound source is located at the coordinates (40, 40). After that it will decrease gradually. The reason for this phenomenon is that when the sound source reaches the middle of the two microphones, the location of the sound source is located in the same line with the two microphones. Although it does not affect the estimation of the microphone array toward the arrival time delay of sound source, the small delay error can cause large positioning error because the positioning algorithm itself is a nonlinear algorithm. So the error of horizontal angle is quite large. Experimental results show that the deviation of the system is under the control range. However, in the real plant environment, the distance between the relief valves is very large. Hence, the error less than five degree can effectively distinguish the take-off safety valve position.

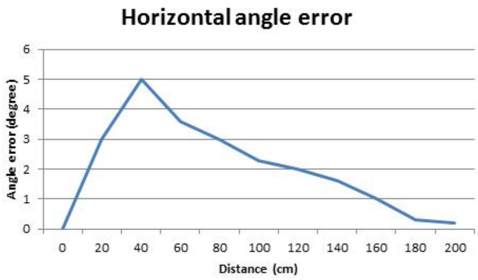

Figure 2: The Angular Error of Acoustic Source Location

6. Conclusions

On the basis of sound wireless sensor, location algorithm and acoustic identification algorithm, a safety production monitoring system is designed in this paper so as to locate the take-off position of the factory safety valve. First of all, we introduce and analyze the working principle of the safety valve. Secondly, the principle of using acoustic sensors to locate is analyzed, and the localization algorithm and recognition algorithm are placed emphasis on. Finally, based on the above research, a safety valve locating system is designed, which has high speed, low energy consumption and less node arrangement. Through the experimental verification, the system designed in this paper can be effectively used in the production of safety valve monitoring, which can reduce the inspection of people and reduce the occurrence of accidents.

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