DESIGN OF EXPLOSION-PROOF CONTROL SYSTEM FOR LIQUEFIED PETROLEUM GAS TANK LEAKAGE BASED ON DATA FUSION

by

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Aiming at the problems of low system efficiency and high energy consumption of nodes in the current explosion-proof control system for liquefied gas tank leakage, a data fusion-based explosion-proof control system for liquefied gas tank leakage is designed. The function design of the explosion-proof control system for liquefied gas tank leakage is completed through personal information management, authority management, basic data management, detection and alarm design and control design. In software design, data fusion algorithm is used to fuse the underlying data of the system, which saves data traffic and ensures the normal functioning of the mobile terminal. The specific step is to use the local estimation of each independent sensor in the multi-sensor network, give each sensor a weighted value according to the approximation of the true value, and finally integrate all local estimates to get the whole system. Through function design and software design, the design of explosion-proof control system for liquefied petroleum gas tank leakage is realized. The experimental results show that the system has the advantages of low node energy consumption and high system efficiency.

Key words: *data fusion, liquefied gas tank, explosion-proof control, system design*

Introduction

In China, liquefied petroleum gas (LPG) is usually divided into LPG and liquefied natural gas [1]. Because both gases are colorless, odorless and volatile, when they reach a certain concentration in the air, they will explode in open fire [2]. In the daily application, the leakage of liquefied gas caused by pipeline aging and forgetting to close the valves and other reasons also causes casualties and property losses [3]. At present, due to the rapid development of smart city and Internet of Things technology, explosion-proof control system for the safe use of urban liquefied gas is also developing very rapidly. The liquefied gas tank [4] can be detected by large-scale wired network monitoring system. However, the monitoring platform based on wired network technology is usually set on PC. Its inherent characteristics determine that it has geographical and spatial limitations when it is used, and it requires relevant staff to take a series of measures for the occurrence of dangerous accidents in the field. Usually, liquefied gas tanks are located in restaurants and residential areas [5-7]. In the night or day when no one is watching, if the use of conventional monitoring platform will be due to their own limitations

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and cannot provide timely help to users. The emergence of explosion-proof control system for liquefied gas tank leakage has solved this problem very well. It is necessary to analyze and study the explosion-proof control system for liquefied gas tank leakage.

The explosion-proof control system for liquefied gas tank leakage based on Internet of Things is composed of monitoring center, intelligent control and remote service center. It realizes remote and omni-directional intelligent monitoring of liquefied gas tank. The STC15F2K60S2 embedded microcontroller is used as the bottom controller chip, and RS485 protocol is used to collect sensor data to realize the monitoring of liquefied gas tank. Video monitoring adopts fluorite cloud platform and PLC to control the explosion-proof gas tank leakage. The ESP8266 WIFI module is used to connect the whole system network to AP base station. Through the server management program, users can remotely monitor the data of LPG tank base in any place with network coverage through computer browser or mobile APP [8]. Based on the analysis and summary of the existing clock synchronization technology and the in-service equipment, the architecture of production monitoring system, SCADA system, leakage monitoring system, video monitoring system, voice telephone system and third-party equipment are designed by using NTP, GPS, Beidou, Modbus communication and CIP communication technology. The clock synchronization method of timing equipment and the insertion method of PLC data time label are all needed. The timing schemes of control center, control center, gas transmission station and valve room are formulated to realize the design of explosion-proof control system for LPG tank leakage [9]. The previous two methods consume more energy in the network nodes, which has the problem of high energy consumption. The previous two methods cannot transmit alarms to the client in a relatively short time, which has the problem of low system efficiency.

In order to solve the problems existing in the above methods, the explosion-proof control system for LPG tank leakage based on data fusion is designed. The specific steps are:
- Overall design of explosion-proof control system for LPG tank leakage.
- Functional design of explosion-proof control system for LPG tank leakage.
- The software of explosion-proof control system for LPG tank leakage is designed.
- The effectiveness of the proposed method is verified in three aspects: data fusion accuracy, system efficiency and node energy consumption.
- Conclusion.

Explosion-proof control system for leakage of liquefied gas tank

Overall design

The explosion-proof control system for LPG tank leakage consists of central server, mobile terminal server and mobile terminal. The central server connects to the mobile terminal server and pushes alarm and other related information to the mobile terminal server. After receiving the push alarm from the central server, the mobile terminal server initiates another SMS message and pushes it to the mobile terminal at the next level [10]. Because the central server and mobile terminal servers are connected, but independent of each other, even if one of them crashes, it will not cause chain damage to other servers, and the operation of the original monitoring system will not stop. The WiFi network can improve the speed of data transmission, so that users can access it directly through the internal network. If the situation does not allow the coverage of WiFi network, then use the way of 3G to VPN to access network data. In this process, we need to add a network firewall to isolate network attacks. The device can connect the communication controller in real time to obtain real-time data synchronization [11, 12].

Considering data security, the mobile terminal device and the mobile terminal server are not authorized to modify or delete the data information of the central server. The only way to read is to avoid the risk of data being destroyed. At the same time, the mobile terminal device is not authorized to save the acquired data, thus avoiding the possibility of data leakage.

Processing requests initiated by users are first transmitted upwards to browsers, and then further requests are sent to many servers through browsers. Finally, the server feeds back the data information needed by users to browsers. Browsers make requests, and their data processing and structure returning to dynamic web page generation can be directly completed by IOS servers. Server content division simplifies the work content of user machines. Most of the work is undertaken by servers. Only a few client application software can be deployed on user machines to achieve the function.

Functional design

(1) Personal information management and authority management

User authentication and authorization mode of the system is to combine password and mobile terminal device number. Both of them need to complete authentication at the same time before authorized login. First, the number of mobile client will be registered, and then assigned to the user's corresponding user name and password. Users use the obtained user name and password to complete authorized login.

The detailed authentication process of user login system is: first, the user opens the designated login page and enters the assigned user name and password at the designated location of the page. If the user name and password are correct, the user can login successfully. After successful login, the user can view personal information, login record and the list of tasks set up. If the user needs to change the password assigned by the system into one, personal password can be applied for password modification on the page. After confirming that the original username and password are correct, the user can modify the new password and the original password will be invalidated. In the duty setting, the user applies for and inquires about the duty task. After all the operations are completed, the user chooses to exit the task system, that is, to terminate the current personal information module.

The function of privilege management module is to manage and distinguish the privilege levels of system users. Usually administrators, ordinary users and so on have different levels of privileges.

(2) Basic data management

The whole system is divided into several modules, each module is independent of each other, which is conducive to the implementation of confidentiality measures, and is connected by protocol between each module.

The system has many projects and wide monitoring contents. The management of multi-site depends on its built-in multi-site management capability, which is conducive to centralized management of many decentralized battle-points from the center, to achieve cluster-based management mode, to establish a network cluster for system management, and to a greater extent to facilitate system management. Multiple sites or virtual hosts can be managed by the same server, and the functional design of the system improves the utilization of the server to a greater extent. Each independent site or virtual host has the ability to manage independently, and the server can allocate appropriate permissions when it manages independently.

Mobile device data access is accomplished by mobile monitoring server, and its configuration is also to meet the realization of data access and management visualization function.

(3) Monitoring and alarm design

In the process of monitoring, the system will send out a lot of alarm information, but the alarm information will be processed hierarchically, and only the most important alarm information will be pushed to the mobile client. The internal alarm system is an independent alarm system, which needs special configuration. Each alarm signal corresponds to an independent bit number. Each alarm signal contains a lot of related alarm information, such as the type of alarm, the time to reach the alarm standard, the user name and contact information of the person who received the alarm. Every alarm signal will be stored and recorded after it is issued. Managers with relevant authority can modify or delete the alarm record. Threshold and specific rules of alarm that meet the alarm standard can be modified by special threads on the server. Once the alarm is initiated, the alarm signal is pushed to the mobile terminals via the server, which uses IOS push technology. Each mobile terminal can view the alarm records and historical alarm records received at present in its operation interface and the users of mobile client can also confirm the operation after receiving the alarm. The system will feed back to the monitoring system server. The users can also contact the alarm contacts according to the information of the alarm contacts.

The whole process of alarm push is shown in fig. 1.

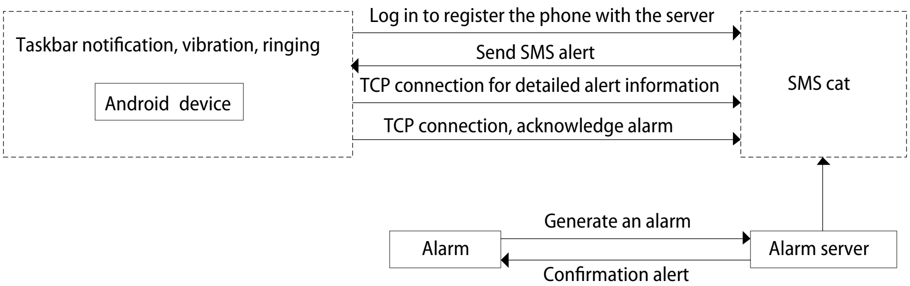

Figure 1. Alarm pushedflow chart

(4) Control system

The system uses single loop temperature control system to control the wall temperature of storage tank. The proposed method uses a single-loop temperature control system and a single-loop temperature over-standard alarm system in parallel. The two systems are connected to different tanks. If it is a single tank, two sets of systems can be connected to the same tank.

Combined with the hardware analysis content, the software content is studied. This section will achieve the design of the control system through the acquisition and fusion of data.

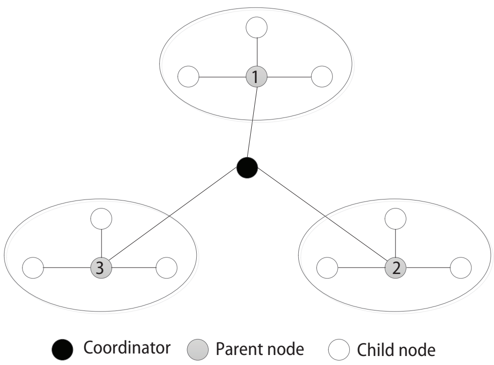

Figure 2. Data fusion model

Software design

The communication mode of wireless sensor in the system adopts Zigbee protocol. The sub-nodes are distributed all over the room. The top-level coordinator collects data from 1, 2 and 3 parent nodes of each type, and finally uploads the data to the server through the Internet of Things gateway. Each node and co-ordinator form a star, tree or network topology through wireless communication, as shown in fig. 2.

Data fusion is carried out on the basis of fig. 2 model. In the system, for a certain measurement value X, such as CO_2 concentration, dust concentration and so on, the results observed by sensors at a certain time are $\{X_i\}(i=1,2,\cdots,N)$. The observation expression of each sensor:

$$X_i(t) = X(t) + E_i(t) \tag{1}$$

where $X(t)$ denotes the true value of the measured value, $E_i(t)$ represents sensor and environmental noise, and the variance of noise is σ_i^2. The weight distribution in the algorithm is based on the magnitude of the sensor disturbed by noise. Finally, the estimated value $\hat{X}$ can be obtained by summing the product of the observed value and the weight value. The expression is:

$$\hat{X} = \sum_{i=1}^{N} W_i X_i \tag{2}$$

where W_i represents the data flux in the control system. The corresponding total mean square error is:

$$\sigma^2 = E\left[\sum_{i=1}^{N} W_i^2 (X-\hat{X})^2\right] = \sum_{i=1}^{N} W_i^2 \sigma_i^2 \tag{3}$$

Equations (2) and (3) showed that the key of fusion lies in the distribution of weights. In some monitoring systems which do not require high accuracy, arithmetic averaging method is used to estimate data. This is a direct operation of data sources, which can achieve basic data fusion requirements, reduce data transmission and reduce errors.

For arithmetic averaging method, its essence is similar to weighted data fusion algorithm, but it omits the calculation of weights and sets the same weights for each sensor directly. The system mean square error obtained by this method is obviously not the smallest. It can be seen from eq. (3) that the total mean square error is a quadratic function of the weighting factors of each sensor, so the total mean square error must have a minimum value. According to the extremum theory of multivariate function, the minimum value is the extremum value of multivariate function when the weighting factor satisfies the constraint condition $\sum_{i=1}^{N} W_i = 1$. After calculation, the expression of the weighting factor is:

$$W_i^* = \frac{1}{\sigma_i^2 \sum_{i=1}^{N} \frac{1}{\sigma_i^2}} \tag{4}$$

The corresponding minimum mean square error is:

$$\sigma_{\min}^2 = \frac{1}{\sum_{i=1}^{N} \frac{1}{\sigma_i^2}} \tag{5}$$

From the eq. (5), the problem of estimating weighted coefficients can be transformed into the estimation of variance of sensors.

Before estimating the sensor variance, the whole system should be analyzed first. Generally, system analysis is divided into horizontal analysis and vertical analysis:

– Transverse analysis is usually based on the results of one sampling of multiple sensors. The variance of sensors can be roughly calculated based on the arithmetic average of the measured values of each sensor. The advantage of this method is that it has good real-time performance and can estimate the sensor variance relatively accurately at each time. The disadvantage is that each measurement requires an estimate of variance, which is relatively time-consuming.

– Longitudinal analysis focuses on the results of multiple sampling of a sensor, and the analysis of a single sensor in a multi-sensor network. The variance of the sensor is based on the estimation after multiple measurements, which combines the comprehensive attributes of the noise inside the sensor and the environmental interference. This attribute exists in the measurement process. This method determines the variance of the sensor after many measurements. It can avoid the calculation of each measurement and save time.

Based on the previous analysis, X_{ji} is used to represent the results of the *j* measurement of the *i* sensor. The variance σ_{ji}^2 of the *j* measurement of the *i* sensor can be calculated by using the variance formula. The weighting coefficient of the sensor can be obtained by bringing it into eq. (4). According to the calculation of the first *j*, the variance of the first $j+1$ is deduced.

The average expression of *j* times measurement is:

$$\overline{X}_j = \frac{1}{j}\sum_{j=1}^{N} X_{ji} \tag{6}$$

The variance expression of *j* times measurement is:

$$\sigma_j^2 = \frac{1}{j}\sum_{i=1}^{j}(X_i - \overline{X}) \tag{7}$$

The variance expression of $j+1$ times measurement is:

$$\sigma_{j+1}^2 = \frac{1}{j+1}\sum_{i=1}^{j+1}\left[X_i - \overline{X}_j + \frac{1}{j+1}(\overline{X}_j - X_{j+1})\right]^2 \tag{8}$$

Combining eqs. (7) and (8), the following formula can be obtained:

$$\sigma_{j+1}^2 = \frac{j}{j+1}\sigma_j^2 + \frac{1}{(j+1)^2}(\overline{X}_j - X_{j+1})^2 \tag{9}$$

The variance of the next moment can be calculated by eq. (9), and only the newly measured values can be substituted. The derivation of sensor variance can simplify the calculation of variance for each measurement. The system can calculate the next sensor variance by using the prior conditions obtained from many measurements and calculations. In this system, the sensor variance used in the overall environment estimation is estimated by this method. The calculated variance is brought into eq. (4) to calculate the corresponding weighting coefficients of the sensor.

In practical applications, each sensor is subject to different interference, so random white noise is added at each constant 1 to simulate the sensor's own interference and environmental interference. After the variance calculation module, the results are substituted into the sub-module of weighted factor calculation. Finally, the coefficients obtained are multiplied with the original simulation data and the fusion values are obtained.

In order to verify the effectiveness and feasibility of this method, it is necessary to carry out the simulation experiment.

Experiments and discussions

Data fusion-based LPG tank leakage and explosion-proof control system, Internet of Things-based LPG tank leakage and explosion-proof control system, clock synchronization-based LPG tank leakage and explosion-proof control system and GPRS-based LPG tank leakage and explosion-proof control system were used to test, and the time spent to push the alarm to the client was compared. The test results were shown in fig. 3.

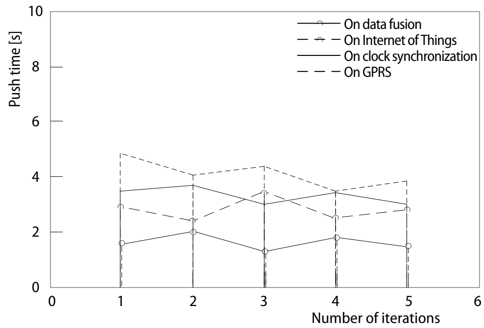

Figure 3. Push time of four different methods

Analysis of fig. 3 shows that the time spent on pushing the alarm information of the LPG tank leakage and explosion-proof control system based on data fusion is less than 2 seconds, which is lower than that of the LPG tank leakage and explosion-proof control system based on Internet of Things, the LPG tank leakage and explosion-proof control system based on clock synchronization, and the LPG tank leakage and explosion-proof control system based on GPRS. It is because this method establishes a specific alarm acquisition channel between the server and JSON, shortens the time of pushing alarm information, and improves the efficiency of explosion-proof control system for LPG tank leakage based on data fusion.

In order to further verify the overall effectiveness of the LPG tank leakage and explosion-proof control system based on data fusion, the LPG tank leakage and explosion-proof control system based on data fusion, the LPG tank leakage and explosion-proof control system based on Internet of Things, the LPG tank leakage and explosion-proof control system based on clock synchronization, and the LPG tank leakage and explosion-proof control system based on GPRS were used for testing. Comparing the energy consumption of four different methods, the test results are shown in fig. 4.

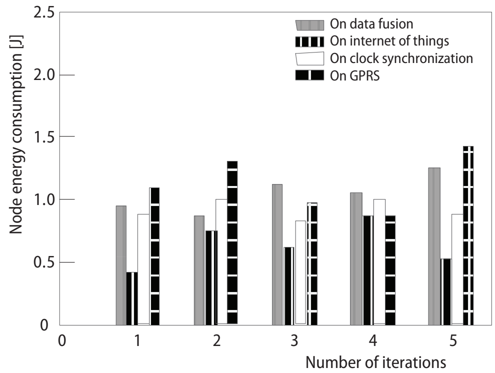

Figure 4. Node energy consumptions of four different methods

Analysis of fig. 4 shows that the node energy consumption of LPG tank leak and explosion-proof control system based on data fusion in multiple iterations is lower than that of LPG tank leak and explosion-proof control system based on Internet of Things, LPG tank leak and explosion-proof control system based on clock synchronization, LPG tank leak and explosion-proof control system based on GPRS, because this method reduces the amount of data transmission and the consumption of mobile traffic. It is verified that the node energy consumption of LPG tank leakage and explosion-proof control system based on data fusion is low.

Conclusion

At present, the world is under the dual pressure of global warming and the development of low-carbon economy, and LPG has developed rapidly because of its clean characteristics. With the increasing demand of major international liquefied gas consumer markets, the pace of global development and utilization of liquefied gas has accelerated significantly, and China has entered a new stage of energy structure adjustment mainly based on gas, making explosion-proof control of liquefied gas tank leakage become a hot research topic. At present, the explosion-proof control system for LPG tank leakage has the problems of high energy consumption and low system efficiency. A leak and explosion-proof control system for liquefied gas tank based on data fusion is proposed. By fusing the existing data in the system, the amount of data needed to be processed in the nodes is reduced, the time needed for data processing is shortened, the existing problems in current methods are solved, and the development and utilization of liquefied gas is guaranteed.

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