Volume 8 Issue 1, 2022
DOI: 10.6919/ICJE.202201_8(1).0005

Summary of Research on Localization of Hazardous Gas Leakage Source

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Abstract

The occurrence of dangerous gas leakage accidents is an important issue faced by the public and society. For example, the leakage of liquefied natural gas, hydrogen and other gases will cause explosion accidents, and the leakage of toxic gases such as ammonia, chlorine, and hydrogen sulfide will lead to poisoning, even suffocation accidents. Therefore, in order to minimize casualties and losses, determining the source of accidental leakage is the primary task; and in the case of accidental leakage, timely and effectively locating the source of gas leakage plays a vital role in emergency rescue. Thus, relevant investigations on the location of gas leakage sources at home and abroad have been carried out, the preliminary process about the location of dangerous gas leakage sources has been introduced: the diffusion model when gas leaks, leak detection technology, the method of obtaining positioning data--sensor arrangement. Meanwhile, common algorithms for gas source localization are introduced from two aspects about active olfactory locating and static gas source locating. Finally, a summary and prospect of the localization algorithm are given.

Keywords

Hazardous Gas, Diffusion Model, Leak Detection, Sensor, Localization Algorithm.

1. Introduction

In recent years, with the rapid development of the industrial economy, the chemical industry has also developed continuously, and the use of hazardous chemicals is increasing, of which a considerable part of hazardous gases such as toxic, harmful, flammable and explosive are widely used. In the process of producing, transporting and storing these dangerous gases, it is likely to be resulting in frequent gas leakage incidents, due to the negligence of relevant staff, operating errors, etc., or because of the long time use of equipment, resulting in aging, equipment problems not repaired in time[1]. Hazardous gases mainly include flammable and explosive gases and toxic and harmful gases. Among the flammable and explosive gases, natural gas, hydrogen, carbon monoxide, hydrogen sulfide, ammonia and some alkanes are common. In the event of leakage, it can explode immediately if encountering fire, heat, etc., once the leakage concentration is high, a small spark can cause a fire or even an explosion. In particular, if the chlorine gas leaks and is fully mixed with hydrogen, it will explode when exposed to strong light; common toxic and harmful gases can be divided into two types:

irritating and asphyxiating. Common irritating gases include chlorine, ammonia, nitrogen oxides, hydrogen fluoride, sulfur dioxide, etc. Once they leak, they will have an irritating effect on human eyes and respiratory mucosa. Common suffocating gases include nitrogen, methane, ethane, ethylene, carbon monoxide, hydrogen sulfide, etc. If a leak occurs and gas is inhaled by the human body, it will cause the body to become hypoxic and even die from suffocation. In addition, the leakage of gases such as sulfur dioxide and nitrogen oxides will cause serious air pollution, causing acid rain and the greenhouse effect. Therefore, the leakage of dangerous gas will cause great harm to the people and the environment. As shown in Figure 1.

(a)Hazardous gas leakage

(b)Fire caused by hazardous gas leakage

Figure 1. Safety accidents caused by hazardous gas leakage

After the dangerous gas leaks, the leakage and diffusion range can cover a large area. The area with large gas concentration is concentrated on the axis near the leakage source and spreads to the surroundings, with the farthest spread in the downwind direction[2]. Therefore, in the event of a leakage, it is vital to locate the leaking source. Locating the source within an effective time, rescue measures can be taken as soon as possible, If leakage source can be used to predict the scope and concentration distribution of the leakage, it can also provide strong data support for the follow-up emergency response of the accident, and reduce casualties and losses as much as possible. Therefore, this article conducts related investigations on the location of gas leak sources and discusses the location methods of gas leak sources. First, it introduces the diffusion model, gas leak detection methods and equipment, sensors, etc. required in the positioning process, after that, the related positioning algorithm is introduced, and a summary of the gas leak source positioning algorithm is given.

2. Process of Gas Source Positioning

The process of gas leak source locating can be divided into the following steps: first select a gas diffusion model, a suitable gas diffusion model can better collect effective concentration data, after, select the gas leak detection method and detection equipment, then arrange the detection equipment according to the diffusion model to obtain the data that needs to be collected. Finally, select different positioning algorithms from the scene, and locate the gas source according to the obtained data.

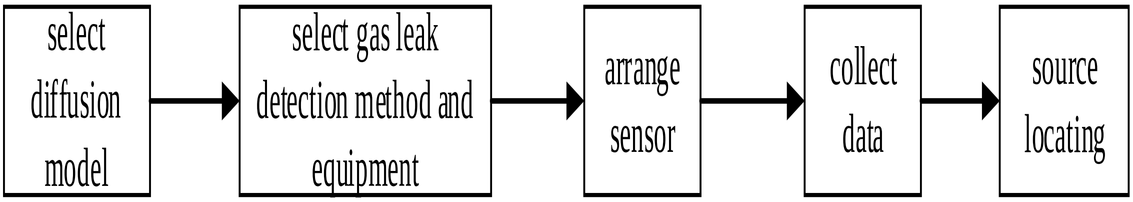

Figure 2. Process of gas source positioning

The gas diffusion model means under given conditions using known parameters combined with numerical calculation and analysis to obtain the relevant laws and characteristics of gas diffusion under actual conditions. Research to solve the diffusion motion of the gas source localization problem is very significant. Understand the law of gas diffusion movement, collect the gas concentration information of some key locations in a targeted manner, and then perform certain processing operations on the data to realize the location of the gas leakage source. The detection of gas leaks is a necessary routine operation. installing of leak detection equipment in the gas storage and transportation site can effectively find danger timely, and quickly take corresponding protective measures against the danger. The arrangement of sensors is related to the data acquisition of leakage source location. The arrangement of sensors should be arranged in combination with different scenarios. In addition to ensuring the effective availability of the acquired data, the issue of arrangement expenses should also be considered to maximize benefits. The data used for gas source location mainly includes wind speed, wind direction, and sensor concentration data. Finally, different methods can be used to estimate the location of the leak source based on the data.

3. Diffusion Model

The gas source location is mainly using the obtained concentration information, wind direction, wind speed information and other data of the leaked gas in the diffusion process to carry out a reverse calculation of the gas source information. In this reverse calculation process, the concentration information is very important. Therefore, in the study of realizing the positioning of the gas source, choosing a suitable diffusion model is the key first step. In the current research, the more common gas diffusion models are: Gaussian model, FEM3 model, BM model, Sutton model, etc.[3-7].

3.1 Gaussian Model [3]

The Gaussian model assumes that the gas concentration distribution is a certain form of normal distribution, which includes Gaussian plume model and Gaussian puff model.

The Gaussian plume model is suitable for the diffusion of continuous leaking sources, that is, for leaking sources that are known to release gas at a constant emission rate during the leak, the model expression is [4]:

$$C(x,y,z)=\frac{q}{2\pi u\sigma_y\sigma_z}exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right)+exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right] \tag{1}$$

$C(x,y,z)$ the time-integrated concentration of the leaked gas at the point (x,y,z); q is the source strength (the release rate of the gas); u is the average wind speed at the effective release height; H is the effective release height; σ_y, σ_z re the standard deviations of the plume concentration distribution in the lateral and vertical directions at distance x.

The Gaussian puff model describes the gas release in segments within a period of time or sudden release in a short period of time, which is a transient leakage source diffusion; the release time is shorter than the diffusion time, and the concentration function of the dangerous gas is shown in the formula (1.2), the meaning of each parameter in formula (1.2) is the same as formula (1.1).

$$C(x,y,z)=\frac{2q}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z}exp\left(-\frac{x^2}{2\sigma_x^2}\right)$$
$$exp\left(-\frac{y^2}{2\sigma_y^2}\right)exp\left(-\frac{z^2}{2\sigma_z^2}\right) \tag{2}$$

The Gaussian model is only suitable for the simulation of neutral gas leakage diffusion, and its simulation accuracy is poor, but there are many relevant experimental data and it is relatively mature.

3.2 Sutton Model[5]

Sutton model uses the statistical theory of turbulent diffusion and the solution of turbulent diffusion coefficient to deal with the turbulent diffusion problem. The function expression of Sutton model is shown as below, and the meaning of each parameter is the same as the Gaussian model:

$$C(x,y,z)=\frac{q}{\pi u\sigma_y\sigma_z}exp\left(-\frac{y^2}{\sigma_y^2x^{2-n}}\right)$$
$$\left[exp\left(-\frac{(z-H)^2}{\sigma_z^2x^{2-n}}\right)+exp\left(-\frac{(z+H)^2}{\sigma_z^2x^{2-n}}\right)\right] \tag{3}$$

3.3 FEM3 Model[6]

FEM3 model is a three-dimensional computer model, which is designed to simulate the atmospheric diffusion of a gas leak. This model has been widely used to simulate continuous release and limited continuous release. Because FEM3 is completely three-dimensional, it can also handle complex flow and diffusion scenarios on variable terrain and around obstacles such as buildings, and has a wide range of versatility. However, this model has the disadvantages of complex simulation calculation, large amount of calculation and time-consuming. The main calculation formula is shown in (1.4).

$$\begin{cases}\frac{\partial(\rho u)}{\partial t}+\rho u\nabla u=-\nabla p+\nabla\left(\rho K^M\nabla u\right)+(\rho-\rho_h)g\\ \nabla(\rho u)=0\\ \frac{\partial\theta}{\partial t}+u\nabla\theta=\frac{1}{\rho C_P}\nabla\left(\rho C_P K^\theta\nabla\theta\right)+\frac{C_{PN}-C_{PA}}{C_P}\left(K^W\nabla W\right)\nabla\theta\\ \frac{\partial W}{\partial t}+u\nabla W=\frac{1}{\rho}\nabla\left(\rho K^W\nabla W\right)\\ \rho=\frac{PM}{RT}=\frac{P}{RT\left[W/M_N+(1-W)/M_A\right]}\end{cases} \tag{4}$$

In this formula, u is the velocity; ρ is the gas density; p is the pressure deviation of the static isothermal atmosphere with the corresponding density ρ_h; g is the acceleration of gravity; θ is the potential temperature deviation from the adiabatic atmosphere at θ_0; W is the mass fraction of the diffusing gas; K^M, K^θ, K^M re the diffusion coefficients of velocity, temperature, and concentration; C_{PN}, C_{PA} are the specific heat capacity of the diffusion gas, air and mixed gas; P is the absolute pressure; R is the universal gas constant; M_N, M_A are the molecular masses of the diffusion gas and air; T is the absolute temperature; M is the molecular mass of the mixed gas; t is the time.

3.4 BM Model[7]

BM model is composed of a series of computer diagrams drawn from experimental data of heavy gas release. It is also called a phenomenological model, which is an empirical model. Relevant researchers performed multiple heavy gas diffusion simulations in the laboratory and field experiments, collected the data obtained from the simulation, connected the data in a dimensionless form, and finally drew the graph in a way that matches the data to obtain the BM model[8]. This model is mostly used to simulate the instantaneous or continuous release of the surface or bulk source diffusion of heavy gas, which is easy to understand, but it performs poorly in terms of extension. Its function is shown in formula (1.5) and (1.6) .

$$\frac{C_m}{C_0} = f_c\left[\frac{x}{\left(V_{c0}/u\right)^{1/2}}, \frac{g_0 V_{c0}^{1/2}}{u^{2/5}}\right] \tag{5}$$

$$\frac{C_m}{C_0} = f_i\left[\frac{x}{V_{i0}^{\ 1/3}}, \frac{g_0 V_{i0}^{1/3}}{u^2}\right] \tag{6}$$

Formula (1.5) and formula (1.6) are the distribution functions of continuous release and instantaneous release. C_m is the maximum concentration of the arc at distance x , C_0 is the initial gas cloud concentration; V_{c0} is the continuous volume flux of the initial gas cloud; V_{i0} is the instantaneous volume flux of the initial gas cloud; u is the reference wind speed at 10m; g_0 is the relative density of the initial gas cloud, $g_0 = g\left(\rho_0 - \rho_a\right)/\rho_a$,where g is the acceleration of gravity, ρ_0 , ρ_a are the initial plume density and ambient air density respectively; f_c , f_i are generalized dimensionless functions.

For the above models, the characteristics can be sorted out and summarized in Table 1[4,9-10]. The diffusion parameters in the Gaussian model, BM model and Sutton model are calculated by statistical methods based on large-scale gas diffusion experimental data. They are not suitable for small and medium-scale diffusion of combustible gas and toxic gas, which may cause certain errors; FEM3 model is a three-dimensional finite element model, which can be applied to any leakage diffusion scene, any terrain and any weather conditions, but the calculation is more complicated.

Table 1. Features of five diffusion models

Model Name	Suitable Objects	Application Scope	Features
Gaussian plume model	Neutral gas	Continuous point source	Easier to operate, less calculation, poor accuracy, not suitable for small and medium scale diffusion of flammable, explosive and toxic gases
Gaussian puff model	Neutral gas	Instantaneous point source	
Sutton model	Neutral gas	Continuous, instantaneous	Easier to operate, less calculation, poor accuracy, and large errors in simulating combustible gas leakage
FEM3 model	Heavy gas	Unrestricted	Wide applicability, better accuracy, difficult operation, large amount of calculation, and not accurate enough to deal with instantaneous leakage
BM model	Neutral or heavy gas	Continuous, instantaneous surface and volume source	Easier to operate, good experience, less calculation, average precision, not strong extension

4. Gas Leak Detection

4.1 Gas Leak Detection Technology

When there’s a gas leakage accident, it’s very important to detect gas leakage. If the gas leakage can be detected timely and effectively, it can provide a data source for the positioning of the gas source and provide a more powerful data support for the subsequent emergency rescue processing.

According to different detection element, gas leak detection methods can be divided into pressure change detection, flow detection, mass spectrometry detection, concentration detection, infrared imaging detection, ultrasonic detection, etc. [11].

Pressure and flow detection are often used in pipeline gas leakage detection such as natural gas. The detection method is to arrange some flow meters or pressure sensors on the pipeline according to a certain distribution, and obtain the flow or pressure information of the gas in the pipeline through the installed equipment, then process and judge the acquired information and data, and finally determine whether there is a leak[12]. The use of negative pressure wave for leak detection is a widely used detection method. Because of its fast response speed, it can quickly locate the leak location, just calculate the time difference between the propagation speed of the negative pressure wave and the pressure signal obtained at both ends of the pipeline [13]. For example, Li[14]et al. proposed a leakage location algorithm based on negative pressure wave attenuation, which uses pressure changes to replace time difference, and tests in actual pipelines. Experiments show that this method has a small positioning error and can be well applied to pipeline inspection.

The method of concentration detection is currently mainly to install gas sensors around dangerous gas places, and use sensors to monitor the concentration. The sensor needs to set the concentration threshold range, and needs high recognition accuracy, then determine whether leakage occurs by judging whether the collected concentration information reaches the threshold range[15]. Once concentration exceeds the set safety threshold range, the sensor will send out a corresponding alarm message.

With the development of science and technology, ultrasonic and infrared technologies have developed rapidly, which have been gradually applied to gas leak detection, and achieved certain results[16-17]. Infrared detection is to use the temperature change caused by the gas when it leaks, through infrared thermal imaging and infrared image processing to detect the leak. While ultrasonic detection uses the characteristics of the eddy current generated when the gas passes through the leak hole to generate the ultrasonic wave band, and the leakage detection is performed by analyzing the collected sound wave signal. Ultrasonic gas leak detection does not need to wait for the gas concentration to accumulate to a potentially dangerous threshold concentration, nor does it require physical contact with the gas. It can respond immediately to all types of gas leaks, respond quickly, and is not affected by factors such as weather, wind direction, leak direction, and gas dilution.

4.2 Gas Leak Detection Equipment

According to different detection methods, different detection equipment can be used, such as pressure sensors, flow sensors, gas sensors, photoacoustic sensors, ultrasonic detectors, infrared cameras[18], etc. for gas leak detection. When the amount of gas leakage is small, the pressure sensor may not be able to obtain the data well; while in the actual application environment, in order to be able to monitor a large area, the infrared camera usually needs to be installed at a high place, which may lead to a certain error in the detection of leakage at a low place, and it may be difficult to detect leaks in the environment that are obstructed, airflow, etc., or leaks with low air pressure.

In the research of locating leaked gas sources, the main data relies on concentration data, so gas sensors are often used for detection. There are many sensor products for gas detection in the world. The detection objects can be divided into four categories: flammable and explosive gas detection, toxic gas detection, industrial process gas detection and atmospheric pollution detection. From the detection principle, it can be divided into: semiconductor gas sensor, electrochemical gas sensor, infrared gas sensor, thermal conductivity gas sensor, carrier catalytic combustion gas sensor, solid electrolyte gas sensor, etc.[19]. Among them, semiconductor gas sensors are the most widely used.

In gas detection, the use of sensors can be divided into three types: handheld, movable and static. Hand-held and movable operations are similar. The biggest difference is that movable sensors can better guarantee the safety of personnel than hand-held sensors. The disadvantages of the two are that the scope of monitoring is limited, and continuous real-time detection cannot be performed; the static sensor can detect the gas concentration in real time, but it often needs to be deployed in a large area, and if a wired device is used, the deployment is inflexible and expensive.

When used, gas sensors require high sensitivity, strong stability, strong corrosion resistance, low power consumption, low cost, easy integration, easy use, etc.[20]. For the detection of some flammable and explosive gases, it’s required that the gas sensor must be explosion-proof, and related equipment should also be explosion-proof to avoid accidents such as fire and explosion during the detection process due to equipment reasons.

4.3 Sensor Layout

The distribution of sensors is related to the effectiveness and reliability of data collection, and t also related to the choice of using static sensors or movable sensors to collect data. When choosing to use static sensors, how the sensors are distributed and the number of sensors need to be considered. Wang[21]et al. in the study of multi-point dangerous gas leakage location, selected a 1000m*1000m square experimental area, and distributed 21*21 sensors evenly according to the test site, the large number of sensors’ distribution makes the amount of acquired concentration data larger, which is more conducive to the location of leaks. Similarly, Su[22]et al. conducted a comparative experiment. First, nine sensors were arranged in a field area of 40m*40m, with an interval of 20m between each sensor, that is, the sensors were placed at the center, four vertices and the midpoint of the sides. Second, arranged the sensors in another 20mx20m site at an interval of 10m, and the other layouts are the same as the first site. Through experimental comparison, it is concluded that the sensors are arranged on the leeward side, and if the arrangement is relatively dense, the positioning error is small. Cho[23]et al. arranged the sensors on the fence of the factory, determined the optimal placement of sensors based on the simulation results of the CFD software, and tried to use simple iterative logic to find the sensor position that could detect the concentration of EPRG-2 with the least number of sensors, finally, 11 sensors placed at a specific location on the factory fence can detect EPRG-2 or even higher concentrations.

Using mobile sensors does not need to consider the distribution of sensors too much, but the using number of sensors is a question, to use a single mobile sensor or multiple mobile sensors. The mobile sensor is actually equivalent to a mobile robot, placing the sensor on a movable platform. Zhang[24] et al. used a single sensor to identify contaminants in enclosed spaces. They pointed out that if the sensor is properly placed downwind of the leak source, it is possible to locate the leak source and identify the leak intensity based on a single sensor, otherwise multiple sensors will be needed. Chen[25] et al. proposed a two-step source identification method based on a single sensor. First, a preliminary estimate of the leakage point is calculated based on the data concentration detected by the sensor, then predict the concentration based on the preliminary estimated leakage point, and evaluate whether more concentration data is needed. If more data is needed, determine the position of the concentration data that needs to be measured, move the sensor to the required position, and repeat these operations until there is no need to continue to measure, then obtain the optimal value. The results show that as long as there are enough observations, single-sensor source identification can be realized, but the number of effective concentrated observations is required to be no less than the number of unknown parameters. Ma[26]et al. proposed a multi-robot collaborative detection strategy, and simulated the process of multi-robots searching for leak sources. When robots’ number increased from 2 to 7, the time for multiple robots to successfully locate the leak source decreased; when the number remains the same, the time for multiple robots to locate two leak sources is longer than locate one. The choice of using a single mobile sensor or multiple mobile sensors can depend on the leaked scene. The arrangement of a single sensor is simple and the method is flexible, but the time may be extended; multiple mobile sensors can effectively shorten the time and respond in a timely manner, but it is necessary to ensure that there is no conflict of mobile strategies between the sensors.

5. Localization Algorithm

The existing gas positioning methods can be divided into two types[27]: active olfaction method and static gas source positioning. Active olfaction is a method in which an active olfactory robot equipped with gas sensing equipment, wind speed and direction sensing equipment and a self-positioning system performs active search in the wind field according to the established search strategy, and finally moves to the gas source position to achieve positioning; while the static gas source positioning relies on the gas detection equipment in a fixed position in the wind farm to realize the estimation of the gas source position through cross positioning or model calculation.

5.1 Static Gas Source Positioning

Static gas source positioning algorithms[28] mainly include trilateral positioning algorithms, multilateral measurement positioning methods, centroid positioning algorithms, weighted centroid positioning algorithms, probability-based algorithms, and intelligent optimization algorithms. Among them, trilateral measurement positioning algorithm, multilateral measurement positioning algorithm, centroid positioning algorithm, etc. combined with wireless sensor network are widely used by researchers, and they are relatively traditional gas source positioning algorithms. These algorithms' essential operation is to select a gas diffusion model suitable for specific scenarios, combine the model to convert the gas diffusion concentration value into the distance value from the monitoring node to the gas source point, and then calculate the source point location and retrograde estimation through function calculations[29]. The idea of probabilistic algorithms is to construct a likelihood function with prior information, acquired data and parameters to be estimated as independent variables, and use likelihood function to quantify the deviation probability between the measured concentration and the predicted concentration of each sensor, then put the inferred parameter into the atmospheric dispersion model for concentration prediction, last, maximize the likelihood function by the deviation probability, and then the estimated value of the parameter will be obtained. The optimization algorithms[30] mainly construct the objective function from the two known information of the leaked gas diffusion model and the gas concentration value detected by the sensor at the position that needs to be detected, put the estimated leakage source point into the diffusion model to obtain the estimated concentration value, and compare it with the actual detected concentration value, then find the optimal value by calculating the difference between the two. In the application of these algorithms, objective function is usually constructed by the least square method or the maximum likelihood method. Since the objective function is non-linear and has multiple unknown parameters, according to natural laws and constraints, after repeated searches, reducing difference, the optimal solution will be found.

Optimization algorithms and probabilistic algorithms are mostly used in gas source estimation inversion methods, using ground-based concentration sensor networks to estimate unknown source parameters based on the fusion of concentration measurement values and meteorological data and other prior information. Running the inferred source parameters in the positive atmospheric dispersion model to generate the predicted concentration and compare it with the observed value in the cost function or likelihood function. The ultimate goal is to find the best or most likely match between the predicted data and the observed data[31], the basic process is as follows:

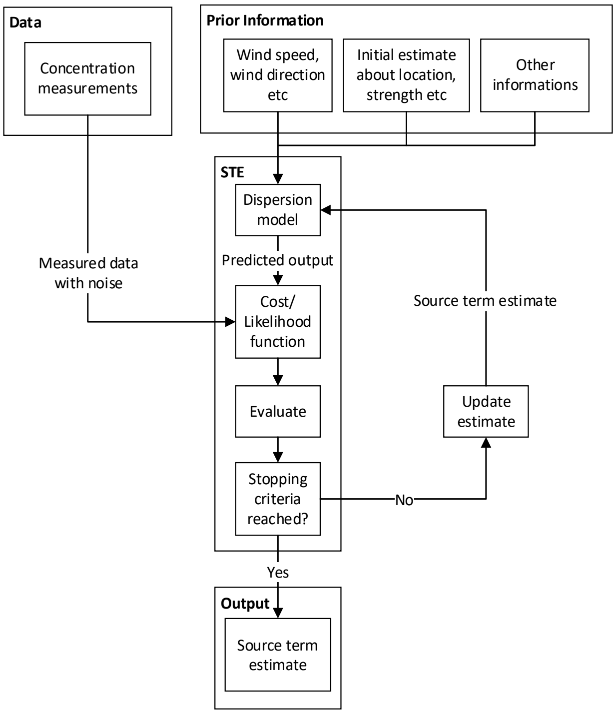

Figure 3. Process of inversion method positioning

Zheng[29] et al. considered that it is difficult to know the concentration of the leak point in the actual gas leakage application, and it is difficult to realize the location through the traditional gas source location algorithm, so they proposed to use an improved weighted centroid location algorithm to initially locate the gas source, and use the preliminary location algorithm to inversely derive the environmental field source parameters, then use the improved weighted centroid location algorithm and genetic algorithm to accurately locate the gas source. They used ethanol gas for experiments, and the experimental results prove that both algorithms can effectively locate the gas leak source, and results have research reference significance for other gas leak source location. Wu[32] et al. proposed a source term estimation model combining gas transportation model, Bayesian inference and slice sampling method to estimate the natural gas leakage source parameters of the underground integrated pipeline gallery, and realized the inversion of natural gas leakage location and leakage rate. This model can provide possible technical support for the loss prevention and reduction of the loss rate of natural gas leakage accidents in urban public utility tunnels. Lu[33] et al., based on the continuous-time model of the particle swarm optimization algorithm, proposed a continuous-time finite-time particle swarm optimization algorithm (FPSO). Through numerical simulation, the effectiveness of the FPSO algorithm was verified. Qiu[34] et al. proposed a fast and accurate source estimation method based on particle swarm optimization and expectation maximization, which used particle swarm algorithm and the EM algorithm to estimate the source parameters, and effectively sped up the convergence speed, and the method was verified in a field study, which proved its effectiveness.

With the development of artificial intelligence technology, machine learning algorithms are also used to locate leak sources, such as random forest algorithms and neural networks. Cho[23] et al. proposed the use of machine learning to track suspicious leak sources in the study of chemical plant leakage accidents. They used computational fluid dynamics (CFD) simulations to derive the sensor monitoring data in the chemical spill accident scene, then used these data to train machine learning models to predict the location of the leak source, and made predictions by deep neural networks and random forest classifiers. Experiments shown that DNN and RF classifiers had excellent performance in chemical leakage tracking, and the proposed method could be used for real-time diagnosis of chemical leakage. Kim[35] et al. optimized based on Cho’s research. They used feedforward neural networks and recurrent neural networks with long and short-term memory to learn the data collected by the installed sensors, and used probabilistic methods to predict the top five points that may have leaks. In order to train and verify the neural network, they also used CFD simulation to generate sensor data. The experiment results predicted well with high accuracy. The results shown that LSTM-RNN was very suitable for solving the problem of real chemical plant leakage source tracking. Zhao[36] et al. developed a helium leak location system using gas sensor networks and machine learning technology, They established a small-scale leakage scenario model, used gas sensors to measure the concentration of helium leaked in the model, generated a data set for the machine learning model, and then used artificial neural network and K-DTW machine learning algorithm to locate the helium leak location, both algorithms can accurately detect and locate the leak location.

5.2 Active Olfactory Gas Source Positioning

Active olfactory gas source positioning means that installing sensor equipment on a mobile robot, the robot can autonomously find the plume of gas leakage through the sensor, track it, and finally confirm the gas source. The positioning process can be divided into three parts: plume discovery, plume tracking, and gas source location. The existing active olfactory gas source localization algorithms mainly include[37]: gradient-based algorithms, biologically inspired algorithms, and multi-robot algorithms. Using a single robot based on the concentration gradient algorithm to locate the gas source is an early work in this field. Biologically inspired algorithms are produced by the ability of organisms to find the source of odors and make path planning. The multi-robot algorithms can sample the gas concentration at different locations at the same time and share it among the robots to guide their movements. These three algorithms have a certain overlap. The bionic algorithms rely on the concentration gradient algorithms to a certain extent. These two are similar in some aspects, but the bionic algorithm often adopts more complex behavior patterns. Multi-robot algorithms also apply gradient-based methods, and some swarm intelligence algorithms (such as particle swarm optimization and ant colony algorithm) are actually derived from organisms, to learn their behavior and collaboration methods from organisms, and apply similar methods in robot collaboration, making the process of finding gas sources faster.

Ishida[38] et al. used the step-by-step method and Z-shaped proximity method[39] as search methods, using gas sensors and wind direction sensors to collect gas concentration data, wind direction, and wind speed data to search and locate gas sources. Later, Ishida[40] et al. further proposed two methods of finding plume through concentration information and tracking plume along the wind direction, and used the two methods to achieve positioning during the repeated process of finding plume and tracking plume[41]. Ma[26] et al. proposed a multi-robot natural gas leak location method based on particle swarm optimization algorithm, and used a search strategy based on particle swarm optimization, ant colony algorithm and cuckoo search algorithm to simulate a single leak source environment. Particle swarm algorithm has certain advantages in controlling the location of leakage sources in multi-robot systems. Liang[42] et al. proposed an improved brainstorming optimization algorithm for indoor turbulent environment, and combined with the headwind search, coordinated robots to realize gas source positioning, which can also be used as a reference for outdoor environments. Cui[43] et al. made a breakthrough in research on the basis of a two-dimensional plane, and proposed a three-dimensional space adaptive gas source positioning method, which used an improved firework algorithm combined with multiple drones for positioning, and used a Gaussian plume model to perform simulation verification. The results shown that the method had high efficiency and universal applicability in gas source positioning.

6. Conclusion

The positioning of the active olfactory method is a process of active search and positioning, which is not affected by specific gas diffusion models and weather conditions such as wind speed and direction. However, it depends to a large extent on the ground environment and the performance of the robot, and there are also certain shortcomings in the search time. A single robot is not suitable for large-scale search, or leads to too long search time and low search efficiency, which affects subsequent emergency rescue; Multi-robots can be applied to large-scale search, but the use of multi-robots will lead to higher costs, moreover issues such as collaboration, information exchange, path planning between multi-robots also need to be considered, the related issues need to be further studied; and the use of robots in the environment of flammable and explosive gas leakage remains to be studied.Yet tatic gas source positioning method can quickly perform positioning calculations by arranging the gas sensor. This method does not need to be close to the gas source to achieve positioning, and the positioning effect is basically not affected by the ground environment; With the rapid development of computer technology, gas sensor technology has made rapid progress, fluid mechanics modeling algorithms have gradually replaced traditional models for gas diffusion simulation, and static gas source positioning technology has been rapidly applied in recent years. Some algorithms in static gas source positioning technology can also be adapted to active olfaction positioning technology after modification, such as genetic algorithm, particle swarm algorithm, gradient descent method, etc. Optimization algorithm still occupies the mainstream position in gas source positioning technology, but with the emergence of machine learning and deep learning, neural networks are introduced into gas source positioning technology. There is no need to consider the gas diffusion model, a large amount of data training is used to estimate and locate the leak source. Compared with other methods, it is relatively simple and may be well applied to rescue work in emergency leak scenarios. It is worthy of further study and discussion.

Acknowledgment

Authors wish to acknowledge the financial support by the National Natural Science Foundation of China Youth Science Found(41701491), the Foundation of the Fujian Province (2017J0146),the National Key R&D Program of China(2018YFB1700500).

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