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Simulation of diffusion trend of unexpected gas leak accident based on google earth

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Abstract
This paper presented a set of methods for dynamic prediction and simulation of the diffusion trend of leaked gas based on Google Earth technology and Gaussian diffusion model targeted at the sudden hazardous chemicals leak accident, providing a set of design solution, and performing the experimental verification for the model and design by taking the example of carbon monoxide, from which the results showed that with the method it quickly and intuitively predicts the gas diffusion trend, provides strong support for the emergency relief and rescue work in case of such sudden gas leak accident.

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Keywords: gaussian diffusion model; google earth; kml; diffusion simulation; emergency rescue

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C(x, y, z)</td>
<td>Time-averaged concentration (kg/m³)</td>
</tr>
<tr>
<td>C(x, y, z, t)</td>
<td>Time-averaged concentration (kg/m³)</td>
</tr>
<tr>
<td>Qv</td>
<td>Total leaked mass flow rate (kg/s)</td>
</tr>
<tr>
<td>Qm</td>
<td>Total leaked quality (kg)</td>
</tr>
<tr>
<td>σx, σy, σz</td>
<td>Diffusion coefficient in x, y, and z-directions (m)</td>
</tr>
<tr>
<td>x</td>
<td>Downwind distance (m)</td>
</tr>
<tr>
<td>y</td>
<td>Horizontal wind direction distance (m)</td>
</tr>
<tr>
<td>z</td>
<td>Vertical wind direction distance (m)</td>
</tr>
<tr>
<td>H</td>
<td>Height of the release source from the ground (m)</td>
</tr>
<tr>
<td>u</td>
<td>Time-Averaged wind speed (m/s)</td>
</tr>
<tr>
<td>t</td>
<td>Dispersion time from the beginning of the leakage (s)</td>
</tr>
<tr>
<td>θ</td>
<td>Wind direction (deg)</td>
</tr>
<tr>
<td>(x, y)</td>
<td>Point in the local coordinate system(m)</td>
</tr>
<tr>
<td>(X₀, Y₀)</td>
<td>UTM coordinates of the origin of coordinates in the local coordinate system(m)</td>
</tr>
<tr>
<td>(Xt, Yt)</td>
<td>Coordinates of this point in the map projection coordinate system(m)</td>
</tr>
</tbody>
</table>

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1. Introduction

China is a large country in terms of chemical production and consumption. Along with the era of reform and opening up, the chemical industry is experiencing rapid development in China; however, the relatively weak production infrastructure for chemicals production has given way to many serious and major chemical accidents which had tremendous impact on the people's lives and health. In particular, in case of a toxic gas leak accident, the easy diffusion property predetermines the hardness in control, the large polluted areas and the tremendous number of affected people. When inhaling a certain amount of toxic gas that exceeds the criterion, people may suffer acute diseases of the respiratory system, cardiovascular and nervous system, and they are under the serious threat to life safety if no timely treatment is available[1]. In addition, comparing with general pollution incidents, a sudden accident often appears ferocious, causing leak of large quantities of pollutants[2] in a very short time. In short, in face of a sudden gas leakage, the safety and fire departments need to make rapid response, determining a complete emergency and rescue plans. Therefore, with the simulation and research of gas diffusion trend, it is of great significance to construct a complete emergency system and engineering deployment by plotting out the time and space distribution of the leaked substance concentration in a short time so as to determine the areas of different pollution degrees after an accident is alarmed.

At present, many scholars at home and abroad have performed a wide range of researches on the basic theory of gas diffusion, presenting a large number of diffusion value simulation models[3-4] and experimental research methods[5], as well as series of researches on the simulations of diffusion trend[6-7], in particular, the research and development in combination with GIS technology[8-10] which show the potential for development with the aim of further application layer based on the intuitive and visual advantages and a wealth of geographic information[11]. It has become one of the main direction of current researches of diffusion trend simulation.

The Google earth launched by Google is an excellent viewer of online Earth image, which has broken through the traditional Web-based GIS data release mode, providing new solution ideas and technical means for the rapid release of the spatial information. With the technologies, the client terminal and the server no longer transmit the spatial data directly, but the (both dynamic and static) images and XML documents. This mode can greatly reduce the burden of the server and network, providing a new idea and solution for the release of spatial data with few changes[12]. The development based on Google Earth, in particular in combination with KML technology[13-14], has become the new trend of development of GIS technology.

This paper presented a method of simulation of gas diffusion trend in case of a sudden gas leak based on Google Earth and KML technology and the engineering example verification is provided. With this method, it can timely, promptly, effectively and intuitively predict the endangered area when a hazardous chemical leakage happens so as to determine the emergency measures and the arrangement of rescue work for a wide range of chemical leakage accidents.

2. Schematic design

2.1. General framework

As shown in Fig 1 the general block diagram, first, the database query for the data and chemical/physical properties are acquired from the sites, which are output to the coordinates in the area representing the three degrees of pollution by this chemical- with low pollution, medium pollution and high pollution- based on the diffusion trend from the calculation based on Gaussian diffusion model; secondly, the coordinate conversion algorithm is used to convert these coordinates latitude and longitude coordinates; thirdly, these latitude and longitude coordinates and different pollution degrees are marked by colors to generate KML files; and finally, the client software of Google Earth is used to input the KML server URL, and then the kml document is transmitted to the client terminal through HTTP protocol, resulting in the display of the diffusion trend on the satellite map. The GUI of Google Earth seems like traditional applications, but in fact, it is a typical B/S system, which can be regarded as the viewer of KML file (similar to web browsers that support viewing of web pages), therefore it supports the concurrent accesses from multiple clients.

2.2. Diffusion model

Gaussian model is used in this paper, which is frequently used in this field; The model can be divided into the following two models base on the leak duration.

(1) Plume dispersion model.

The gas concentration at certain moment at certain point in space is solved by the following formula (1).
\[ C(x, y, z) = \frac{Q}{2\pi \sigma_y \sigma_z} \times \exp \left[ -\frac{1}{2} \left( \frac{y}{\sigma_y} \right)^2 \right] \times \exp \left[ -\frac{(z - H)^2}{2\sigma_z^2} \right] \times \exp \left[ -\frac{(z + H)^2}{2\sigma_z^2} \right] \] \tag{1}

(2) Puff dispersion model.

The gas concentration at certain moment at certain point in space of the puff of transient point source at H height from the ground (CCPS-P88) is solved by the following formula (2).

\[ C(x, y, z, t) = \frac{Q}{(2\pi)^{3.5} \sigma_x \sigma_y \sigma_z} \times \exp \left[ -\frac{1}{2} \left( \frac{x - ut}{\sigma_x} \right)^2 \right] \times \exp \left[ -\frac{1}{2} \left( \frac{y}{\sigma_y} \right)^2 \right] \times \exp \left[ -\frac{(z - H)^2}{2\sigma_z^2} \right] \times \exp \left[ -\frac{(z + H)^2}{2\sigma_z^2} \right] \] \tag{2}

2.3. Coordinate transformation

In this paper, the algorithm for the coordinate transformation process is shown in Fig 2. Firstly, the latitude and longitude coordinates of the source of leakage (i.e.: the origin of coordinates) are converted to UTM coordinates; secondly, the UTM coordinates of the point and the dispersion model are used to calculate the origin of coordinates of all local relative coordinates for all points, which are then translated to UTM coordinates; finally, all UTM coordinates are converted to latitude and longitude coordinates. This algorithm mainly uses the mutual conversion between latitude and longitude coordinates and UTM coordinates with the actual formula[15], and the conversion from local relative coordinates to UTM coordinates with the formula (3) as follows:

\[ X_0 - x \cdot \sin(\theta) + y \cdot \cos(\theta) = X_f \]
\[ Y_0 - x \cdot \cos(\theta) - y \cdot \sin(\theta) = Y_f \] \tag{3}

2.4. KML file

KML is a data file format used to display the geographic information in Google earth, of which the latest version has been adopted by openGIS into international standards. It defines a set of labels used to create and operate various types of geographical features of Google Earth. For complete syntax and information, please see the reference[14]. When the KML is created, it is necessary to note that: (1) KML is a structured XML document, and UTF-8 encoding is required in order to show Chinese correctly in Google Earth. (2) When the KML server output the KML response to Google Earth, the HTTP
response status should be set to 200, while the HTTP content-type response header must be set correctly, where the KML should be “application/vnd the google-earth kml +x”. (3) Because for now the height information in ignored temporarily, the elevation values of all points are set to 0. (4) Colors are used to label the areas of different pollution degrees.

Fig. 2. Process of coordinate transformation.

3. Scheme verification

In this paper, carbon monoxide is taken as the sample gas to perform the experimental verification for the above scheme, where the test platform is a PC of the configuration parameters as follows: Win7 operating system, Core (TM), i3-2100 CPU dual-core 3.10GHz frequency, and 2.00GB memory.

3.1. Experimental parameters

The experimental parameters are shown in Table 1.

<table>
<thead>
<tr>
<th>Dispersion model</th>
<th>Wind velocity (m/s)</th>
<th>Wind direction (deg)</th>
<th>Leakage amount or speed</th>
<th>Leak source Latitude and longitude (deg)</th>
<th>Gas molecular quality</th>
<th>Absolute temperature (K)</th>
<th>Atmospheric pressure (Pa)</th>
<th>Atmospheric stability</th>
<th>Leak source height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plume model</td>
<td>2</td>
<td>270</td>
<td>500kg</td>
<td>(31.2, 121.4)</td>
<td>28</td>
<td>298</td>
<td>1.01 *10^7</td>
<td>F</td>
<td>5.0</td>
</tr>
<tr>
<td>Puff model</td>
<td>2</td>
<td>270</td>
<td>3kg/s</td>
<td>(31.2, 121.4)</td>
<td>28</td>
<td>298</td>
<td>1.01 *10^7</td>
<td>F</td>
<td>5.0</td>
</tr>
</tbody>
</table>

3.2. Trend presentation results

For carbon monoxide, the dispersion trend on Google Earth is shown in Fig 3, where, purple, red and yellow colors represents the pollution degree of a region in the order of heavy, medium and light in relevance to the gas concentration range 10–100ppm, 100–1000ppm, and over 1000ppm. The trend map in combination with Google Earth presents a wealth of geographic information, such as roads, buildings, hospitals and factories etc. which can be a great support for the deployment accident rescue and resource scheduling works.

4. Conclusions

This paper presented a set of methods for dynamic prediction and simulation of the diffusion trend of leaked gas based on Google earth technology and Gaussian diffusion model targeted at the sudden hazardous chemicals leak accident, providing a set of design solution, and performing the experimental verification by taking the example of carbon monoxide.
The scheme mainly uses Google Earth to provide two-dimensional geographic information. In fact, however, Google Earth is a three-dimensional map displaying software, which has another major feature of displaying 3D maps and building models, especially the combination with virtual reality technology; it is one of our research directions in future to monitor the environmental issues such as air quality and air pollution, to monitor the chemical plants, oil and gas pipelines in the three-dimensional space.

![Fig. 3. Illustrations of dispersion trend of the plume model (a) and the puff model (b).](image)

**References**


