GAS DISPERSION FLUID MECHANICS SIMULATION FOR LARGE OUTDOOR ENVIRONMENTS

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1. Introduction

Leaking gases from infrastructure, such as pipelines, industrial plants or landfills, can pose a serious threat to life and our environment. Hence, it is important for both monitoring purposes as well as rescue workers to localise gas leaks efficiently.

Several incidents in the past, such as the gas explosions in Kaohsiung/Taiwan in 2014, have shown that it can be difficult for humans to draw the right conclusions from given gas measurements, because we lack the intuition to interpret the data correctly. To complement this weakness, algorithms can be used that first identify optimal locations to carry out the measurements and in a second step generate gas distribution maps from the measurement data. Given the gas distribution, a human operator or an algorithm can deduce possible leak locations.

However, the development of algorithms for mapping gas distributions and localising gas sources is a challenging task, because gas dispersion is a highly dynamic process and it is impossible to capture ground truth data, especially in outdoor environments. Since experiments are cost-intensive, time-consuming and – most importantly – lack repeatability, fluid-mechanical simulations of the gas dispersion are a suitable way to support the development of algorithms, that can be validated later in real world experiments.

In recent years, some tools for gas dispersion simulation have been developed. Monroy et al. give an overview in [1] and present a new simulator called GADEN. Though this simulator provides more features than its competitors, it is not suitable for simulations of large outdoor environments.

In this paper, we present a concept of how the simulator can be improved to handle both indoor and large outdoor scenarios and give an outlook on future work.

2. Remote gas sensors

In the past, in-situ sensors have been most often used to sense gases. These, however, require direct contact with the gas and are therefore not well suited for scanning large outdoor areas or measuring gas concentrations at elevated locations from the ground. Moreover, moving in-situ sensors through a gas distribution might alter it and thus distort the measured values.

These disadvantages can be avoided by using remote gas sensors based on the Tunable Diode Laser Absorption Spectroscopy (TDLAS). They allow for measuring the concentration of a certain species, for instance methane, by tuning a diode laser from a wavelength, that corresponds to a characteristic absorption line of the species, to a wavelength, that is not affected by the species under measurement. Using the Beer-Lambert law, the concentration can be estimated from the difference of the received signals.

In contrast to their in-situ counterparts, TDLAS sensors cannot measure the gas concentration at a specific point, but provide an integral measurement along their laser beam, as shown in Fig. 1.

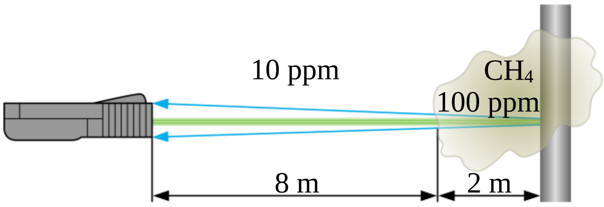

Fig. 1. Remote gas sensors based on the Tunable Diode Laser Absorption Spectroscopy (TLDAS) provide an integral measurement. Here the measurement would read 8 m · 10 ppm + 2 m · 100 ppm = 280 ppm · m.

Often, the laser beam is approximated as a line. However, this does not hold in the real world; instead, the shape of a laser beam can be better described by a cone, which is shown in Fig. 2.

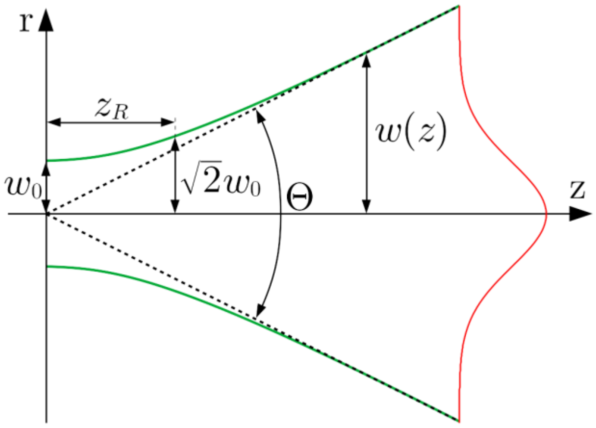

Fig. 2. Parametrisation of a laser beam with a Gaussian intensity profile (red). While Θ denotes the total angular spread of the beam, $w(z)$ is the radial distance at which the intensity drops to $1/e^2$ of its value at the centre.

A typical laser beam of a TDLAS sensor has a total angular spread of about $8.5 \cdot 10^{-3}$ rad and thus yields a spot diameter of 56 cm at a distance of 30 m. Therefore, it can make a significant difference whether the beam is modelled as a line or as a cone, which is also proven in [2]. This fact needs to be considered for the design of the fluid-mechanical simulation.

3. Gas dispersion simulation

The previously mentioned simulator GADEN [1] uses a two-step procedure to simulate a gas dispersion process. In the first step, a wind field is generated using a computational fluid dynamics (CFD) software, for instance OpenFOAM. The shape of the environment, i.e. obstacles from the fluid's point of view, is also taken into account. After this step, the wind field is available as a homogeneously spaced grid.

In the second step, the most relevant gas dispersion effects are used to generate a grid of the same size describing the gas concentration distribution. A typical indoor scenario might have a size of $10\text{ m} \cdot 4\text{ m} \cdot 2.5\text{ m} = 100\text{ m}^3$ and the grid describing this volume might have a resolution of 0.1 m yielding 100’000 cells, which can be easily handled by off-the-shelf personal computers (PC).

However, this approach aims at rather small indoor environments, because large outdoor areas will simply overcharge the simulator. Given a volume of $100\text{ m} \cdot 100\text{ m} \cdot 40\text{ m} = 400'000\text{ m}^3$ and a grid resolution of 0.1 m, the simulator would have to deal with $400 \cdot 10^6$ cells. Storing four float values with double precision per cell, i.e. the 3D wind velocity and gas concentration, each with a size of 64 bits / 8 bytes, the whole grid would occupy $4 \cdot 8 \cdot 400\text{ MB} = 12.8\text{ GB}$ of memory.

This pushes a currently available off-the-shelf PC to its limit. Moreover, one might want to increase the grid resolution to fully capture the cone shape of the laser beam. By increasing it to 5 cm the grid would occupy already 102 GB of memory.

Since gas distributions often only cover a rather small portion of the environment, one can exploit this fact and store a sparse representation. OpenVDB [3] was explicitly developed for this purpose and stores values on a sparse grid in a B+ tree. Fig. 3 shows an example of a gas plume in an environment measuring $80\text{ m} \cdot 80\text{ m} \cdot 30\text{ m}$. While GADEN uses almost 1 GB to store this plume, the sparse storage using OpenVDB occupies 2.3 MB of memory and therefore allows for simulations of large outdoor environments (as long as the assumption of sparsity holds).

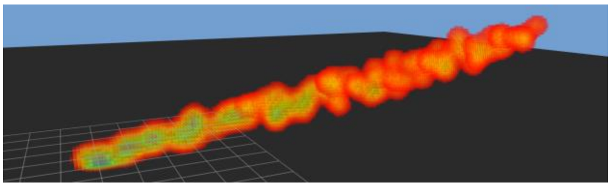

Fig. 3. Gas plume created with GADEN. The plume has a length of approximately 20 m and reaches a diameter of up to 3.5 m. The grid resolution is set to 0.1 m.

4. Conclusion and future work

By exploiting the sparse structure of gas distributions, a simulation of gas dispersion in large outdoor environments becomes possible. However, the description of the wind field still needs to be addressed, since this is affected by the same limitations when the resolution is increased. To some extent, this also applies to the description of the environment. Future work will address both issues and compare the results to well-established CFD software.

References

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