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DETECTION OF HAZARDOUS GAS DISPERSION BASED ON SENSOR EQUIPPED MICRO-AERIAL VEHICLES AND EMERGENCY RESPONSE MODELING

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Abstract: Several air dispersion models are available for the prediction and simulation of the hazard areas associated with accidental releases of toxic gases. The estimation of the source term is crucial for the model result and often affected by large uncertainties in the case of an emergency: the size and location of the leak are difficult to determine and the amount of the released chemical is usually unknown. In these cases, an estimation of the source term based on assumptions is needed. A possibility to reduce these uncertainties in emergency response modelling is the estimation of the release rate ("back-calculation") based on real-time chemical measurements (whenever available). A few dispersion models for hazardous gas releases have been adapted to incorporate real-time chemical measurements and have been tested with in-situ data from field experiments. In the frame of an ongoing research project SkyObserver, the usability of airborne measurements from a group of sensor equipped micro-aerial vehicles (MAVs) to provide real-time data for release rate estimation is investigated. A modelled first-guess of the hazardous gas dispersion is used for the mission planning. The MAVs are networked and coordinate their routing dynamically within the group so that no collision occurs and that the mission area is covered optimally according to a cost function. First results of the project are presented and discussed.
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Key words: *micro-aerial vehicles, hazardous gas releases, dispersion modelling*

INTRODUCTION

In the case of emergency situations like accidental release of toxic substances the sensing and the prediction of the possible damage is of highest importance for the planning of the proper countermeasures. Another important aspect is the fast detection and location of injured people, which often is time consuming and dangerous for the rescue squads themselves. Both tasks are essential for the coordination among the emergency responders in real case situations.
Sending at first the MAVs in the toxic area reduces the risk for the first responders and helps them to better organize and coordinate the evacuation action (when necessary) as well as giving them more concrete information about the protection equipment needed. The application of the MAVs can be divided into several sections. At first a general overview picture of the situation and the affected area will be created in order to support the emergency responders. Second step will be the detection of "moving persons" (including a live picture), which will definitely speed up the rescue measures and additionally help the general coordination of the action. First guess model calculations of the dispersion of the hazardous plume are used as input for the mission planning. The chemical measurements are on the other hand used as an input for more precise dispersion calculation (using a source term back calculation approach).

An essential question for a technical development as presented here is whether the costs of the system are justified by the value that can be expected after the achievement. One aspect to be considered in this context is the probability of occurrence of severe chemical accidents. As pointed out by M. Struckl (2007), the databank MARS (Major Accident reporting system) of the EU commission reported a more or less constant number of registered industrial chemical accidents (chemical accidents according to the SEVESO II Directive) between 1994 and 2004 with an average of about 25-30 accidents per year (Figure 1). In 45 % of these reported cases, hazardous gases were released directly. In 28 % of the cases, the accident occurred in connection with fire and in 27 % of the accidents hazardous gases were released in an explosion.

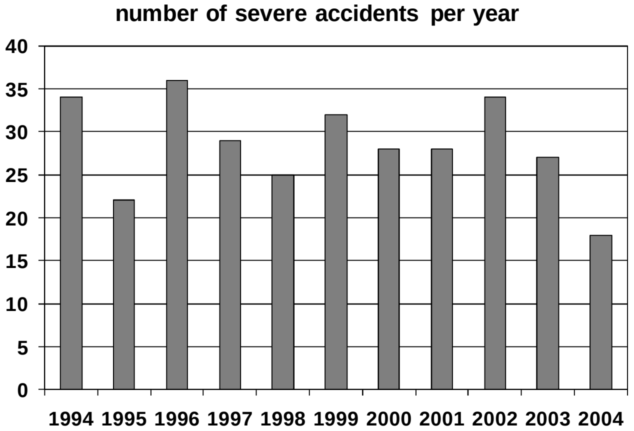

Figure 1.Number of reported severe chemical accidents in Europe between 1994 & 2004 (after Struckl, 2007).

METHODOLOGY

Micro-aerial vehicles

The micro-aerial vehicles (MAVs) will operate in a group, where a minimum of 3 MAVs is needed in order to fulfil the above mentioned tasks.

The prototype of a MAV is depicted in Figure 2. Every MAV system contains several MAVs and a ground station. Depending of the operation the MAVs will be equipped with one or more sensors: MAV with sensors for toxic substance, MAV with a camera for obtaining an overview picture, MAV equipped with a special camera for detection of persons and transfer of live pictures. The ground station serves as a configuration and parameterisation, as well as for manual adaptation (by demand) of the system for the real time application.

The constructed MAVs will fly and investigate in a predefined cell, but rather not rotating along a centum. The flight will be repeated several times. The duration of the flights cannot be longer than 20 minutes and the MAVs are piloted automatically. The first area picture, depending on the application time of the MAVs and the operation duration can be obtained after 15-30 minutes. The time and coarse intervals between the measurements will be chosen in respect to the reaction time of the sensors and the dispersion model requirements. The automation of the flight reduces the risk for the first emergency responders, where after obtaining more correct and detailed information about the amount of the toxic substances, so better countermeasures can be applied. The maximum area, covered form the MAVs is about 2x2 km, and the minimum resolution is 5 cm.

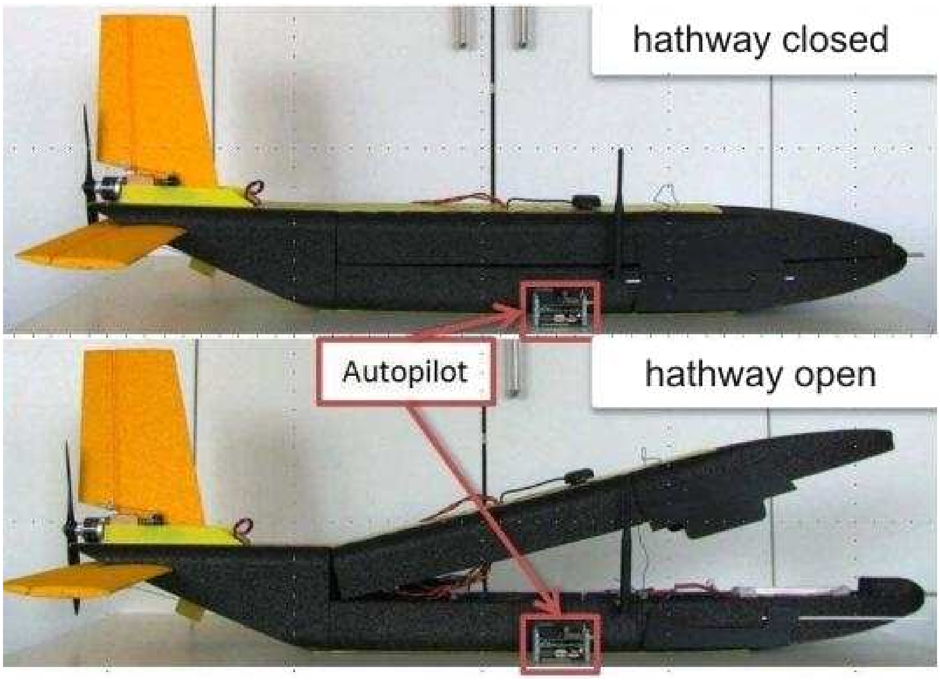

Figure 2. Prototype of the MAV (without wings, with autopilot).

A special algorithm for the detection of persons, based on the camera videos will be developed. For the camera application the following features should be considered: a very good resolution (5 cm), small weight, temperature area and integration of the MAVs. Important for the real time application is the optimisation of the algorithm in order to detect injured persons in real time.

The planning of the flight trajectories is based on the “first guess” calculated with a dispersion model. The next step is to evaluate the first estimate with back calculations by precocious and continuous concentration measurements made in the toxic plume from the MAVs.

On-board computer vision system

An on-board computer vision system is under development as an optional module for the MAV and has to fulfil the following main-tasks:

- Detection of persons moving on the ground
- Acquisition of an overview image
- Live video for the detection of blocked access routes

In case of a chemical accident it is likely that an evacuation of the entire endangered population is not possible in time, especially for chemical plants that are located close to urban environments. Here, a first solution is to instruct people to find shelter in nearby buildings, closing windows and doors to avoid a high gas concentration within the building. Thus, the task of the computer vision system is to detect people that are trying to escape from the scene, being without a shelter. Detecting

these people in a short time span is essential for the fast preparation of rescue missions, enabling relief units to specifically rescue those people first who are exposed to the highest gas concentration.
For the design of this person detection system it is necessary to process the data on-board the MAV in real-time, highly reducing the load for the radio transmission between the MAVs and the base station. Therefore a light-weight embedded vision system is required that comprises image acquisition as well as a processing platform. An embedded vision system that is highly amenable for our purpose is the VCSC4012nano, called "Smart Camera" from Vision Components.
This vision system is depicted in figure 3 and consists of a 1/2.5" CMOS sensor with a resolution of 2592x1944 pixels and a 400MHz TMS320DM640 fixed point DSP from Texas Instruments at a total weight of about 40g, already including the S-Mount lens.
For the detection of moving persons, it is necessary to calculate the images' optical flow. Here, we are using correspondence algorithms initially designed for the application of stereo vision (Ambrosch, 2009). Rather than searching along the epipolar lines as performed for the stereo computation, the correspondence is searched for a defined area taking into account the MAV's speed over ground as calculated by the autopilot system as well as the a priory knowledge about the maximum speed of humans. Furthermore, the signature of humans is used to extract moving persons from other moving objects as well as moving shadows (clouds) and reflection.

Figure 3. VCSBC4012nano

To deliver a high resolution image of the affected area that allows for conclusions about the cause for the chemical accident in a short time span, it will be possible to use the MAVs also for the acquisition of multiple overlapping overview images, covering the whole scene. These images are stored in the MAVs since a direct transmission to the base station would exhaust the bandwidth of the radio transmission. Thus, these images are accessible as soon as all images are acquired and these specific MAVs returned to the base station. Then, the images are transferred to the base station and stitched to allow for one high resolution image of the overall affected area.
Depending on the number of MAVs dedicated to the acquisition of the images and the overall size of the captured area, the high resolution overview images should be available within 15-30 minutes.
To allow the relief units to define access routes for rescuing unsheltered persons, it is possible to access the live video acquired by one of the MAVs that are equipped for the person detection, directly from the base station. This way, blocked streets can be detected and diversions found, avoiding that the relief units are stuck on their way to the accident.

Source term back calculation
The background idea of the Advanced Back Calculation (ABC; Shahryar and Gilbert, 2003) involves "reverse calculation" with a dispersion model: Usually the release rate is used as an input to the dispersion model and the results are the concentration field for the affected area, while the ABC utilizes the concentration filed data to estimate the release rate. The back calculation algorithm takes into account the spill location, time of release and measured concentration to estimate the release rate. The ABC provides the emergency responders with a possibility to reduce uncertainties in the source term, based on real time chemical measurements (whenever available). The five base components in a back calculation assessment are: gas detection sensors, meteorological measurements, release location, starting time of the release and sophisticated dispersion model. The ABC approach as implemented in the emergency response software of Safer Systems will be tested in the Skyobserver project using data measured with MAVs.

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