Micro-Drone for Gas Measurement in Hazardous Scenarios via Remote Sensing

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Abstract: - The Federal Institute for Materials Research and Testing and the company AirRobot GmbH & Co. KG cooperate to develop a flying remote-controlled measuring system. The system is capable of operating in a variety of scenarios of gas emission, e.g. exhaust gas from a chimney, flue gas in case of a fire, gas emission in case of an accident of chemical or hazardous goods or in case of a terrorist act involving toxic gases. Another addressed field of application is spatially resolved emission control of geodynamic active regions, waste disposals, stockpiles, CO_2 storage areas (CCS), industrial sites and pollution critical areas. Due to its mobility the system can measure the gas concentration in the immediate vicinity of the object which causes the emission. A further stage of extension is to enhance the system for plume-tracking and identification of gas sources.

Key-Words: - Remote Sensing, Micro-Drone, UAV, Gas Measurement, Emission Control, Data Mapping, Monitoring, Plume Tracking

1 Introduction

At present time, the release of critical gases is an acute threat and mainly responsible for a multitude of immense dangers and problems – both global (ozone hole, global warming, climate change) and local (smog, pollution, poisoning danger in case of an accident or terrorist attack). The gas release can take place in many different ways with different backgrounds: as exhaust from traffic or industry, as flue gas from volitional or unintentional fires, as a consequence of a chemical or dangerous goods accident, or as the result of a terrorist attack.

The fundamental requirement for gas emission control and effective counteractive measures is the identification and quantification of the relevant gas concentration in the immediate vicinity of the source. For measuring gas concentrations in many different scenarios of gas release, a flexible and mobile measurement device is needed. The state of the art measurement systems used in actual scenarios fulfill these requirements only partially and show further constraints: measuring vehicles equipped with appropriate gas analysis technology can certainly carry out highly selective gas measurements, but they are generally ground-based and cannot reach the emission source. Smaller handheld measurement devices are flexible and inexpensive, but endangering people prevents their use very close to the emission source.

An even greater technical challenge is the airborne search for hazardous gaseous substance sources which has great significance e.g. in the field of leak detection, monitoring of disposals or geodynamic active areas and fight against terrorism. In many areas this is an unsolved problem. Many methods of mobile robot navigation to locate sources of hazardous materials are based on the search behavior of insects and other animals, which use their olfaction to locate food, to detect danger or even to find mates. They are well known in the literature [1] under the topics “odor-source localization” and “plume-tracking”. Implementations of these methods have been tested and evaluated so far on ground-based robot platforms, AUVs (Autonomous Underwater Vehicles) and simple structured blimps.

The objective of this work is to implement a micro UAV (Unmanned Aerial Vehicle; also referred to as micro-drone) for the measurement of gas concentrations. Additionally, an airborne route planning and optimization strategy has to be realized for the localization of gas emission sources.

2 Development of a Mobile Measurement System

2.1 Development of the Equipment Technology

Recent developments in the field of mini UAV and mobile gas measurement technique have established new possibilities to search for and characterize hazardous airborne substances. The Federal Institute for Materials Research and Testing (BAM), in cooperation with the AirRobot GmbH & Co. KG company, has developed a mobile and flexible measurement system as part of a R&D project funded by the Federal Ministry of Economics and Technology (BMWi). The concept of the project includes the development of a gas sensor module for the AirRobot drone AR100 (Fig.1), which can be used in different scenarios. Validation and optimization of the system is also part of the project.

Fig. 1. AirRobot AR100

The compact design and excellent manoeuvrability of the remotely controlled quadrocopter (AR100) make possible precise navigation and enable the device to enter small passages. The maximum payload weight amounts to 200 g, with a total flight weight of about 1.3 kg. The diameter of the AR100 is 1 m. The maximum flight time is about 30 min. at a maximum wind load of 8 $m\ s^{-1}$. A powerful wireless radio link enables the communication of the ground station with the AR100 and its payload and includes both the control and the data transmission units of the payload. The operating distance of the remote control is 1 km. The AR100 can be flown by sight and via onboard video camera and head-up display.

A commercially available 5 gas detector was used in the AR100, which was originally designed for the personal safety. For this reason the device features low weight and compact design. The modular concept allows the ad hoc exchange of sensors in the gas detector, which enables users to customize it for their specific application. Depending on the scenario, the gas detector can detect many combustible gases and vapours (catalytic Ex sensor) as well as different hazardous gases e.g. O_2, CO, H_2S, NH_3, CO_2, SO_2, PH_3, HCN, NO_2, Cl_2 (electrochemical sensors). A significant reduction in weight has been achieved by the removal of unnecessary components and the provision of a rechargeable battery. Hence, the total weight of the gas detector amounts to less than the payload limitation. A more lightweight lithium-based battery buffers the sensors until their next mission to achieve fast operational readiness. An Additional electronic circuit controls the communication between the gas detector and the drone via appropriate device interfaces. A temperature and humidity sensor was also integrated as both factors may affect the measurement data. The case of the gas detector is protected against water and dust according to IP 67 and therefore capable of working outdoors.

Gas transport to the chemical sensors is a critical process. This is due to the rotors of the quadrocopter and the turbulence caused by them. Various solutions are available depending on the application and basic conditions. The gas transport can take place passively (without any auxiliary device), semi-actively (using the air flow generated by the rotors) or actively (using an additional fan). When using the passive principle, the T_{50} / T_{90}[1] times of the sensors are relevant. In order to achieve faster measurements with less residence time of the drone the other two gas transport principles should be applied.

2.2 Development of Evaluation Algorithms

By combining video data, flight control data, GPS coordinates (Global Positioning System) and measurement data from the gas sensors a new method to access the expansion and the dispersion of specific gases should developed. The objective is to coordinate adequate measures e.g. local evacuation. In addition a data base for the self-optimizing search (plume tracking) of hazardous gaseous substance sources is provided. For this purpose, the sensor system of the inertial measurement unit (IMU) will be used to determine wind speed and direction. The IMU is an important part of the drone. It provides the basis for flight control and can be readout in operation. The IMU consists of three orthogonally arranged accelerometers, which detect linear accelerations along the x-, y- and z-axes, and three orthogonally arranged rotation rate sensors, which measure angular accelerations along the x-, y- and z-axes. Magnetic field sensors (compass) and GPS are used to improve the accuracy of the IMU and to compensate for sensor drift [3]. The IMU of the AR100 also contains a barometric pressure sensor to control the drones' altitude.

Existing search algorithms will be analyzed for their adaptability to micro-drones and, if applicable, a porting will be accomplished. The combination of existing and the development of new search algorithms offer further possibilities. The results will be simulated by CFD (Computational Fluid Dynamics) methods and evaluated and validated by field tests.

Corresponding user software will be developed to control and configure the gas detector and to allow the data evaluation and storage. It should cover all important

[1] "The response time of the sensor is commonly specified by the T_{90} or T_{50} time. T_{90} is the time for the sensor's response current to reach 90% of its steady-state value. Similarly, the T_{50} metric is the time required for the sensor to reach 50% of its steady-state value [2]."

information and accordingly enable estimating the gas dispersion and risk potential. Thus proper counteractions can be initialised promptly and a localisation of the emission source can be started.

3 Validation Experiments in a Test Chamber

Experiments in laboratory scale were carried out in a 20 m³ test chamber to measure different CO_2 concentrations for the validation of the system with respect to the measurement of gas concentrations in a medium-sized volume consisting of the same gas. Two commercially available gas detectors which were placed at different positions in the chamber were used as reference systems. One of them was identical to the one used in the drones' payload. A circulating pump and another fan were used to achieve a homogeneous intermixing of the entire volume. The chamber was flushed at the beginning of each trial i.e. the contained gas / air mixture was replaced with "clean" air to assure a CO_2-free test chamber. The induction of CO_2 was carried out in series and intermittently for about 30 s to regulate the CO_2 concentration. In the first trial the AR100 was started after CO_2 had been introduced into the chamber. In the second trial the AR100 was started before CO_2 was induced.

By taking into account the accuracy of the used CO2 sensors of the different measurement devices used and the position-dependent delay[2], all values measured by the device of AR100 coincide with those measured by the reference devices (Fig. 2). Therefore, the ability of the entire system to measure gas concentrations in a large-volume plume has been verified. As a further step the enhancement of the design and optimization of the system are being planned to implement a more pointwise gas concentration measurement.

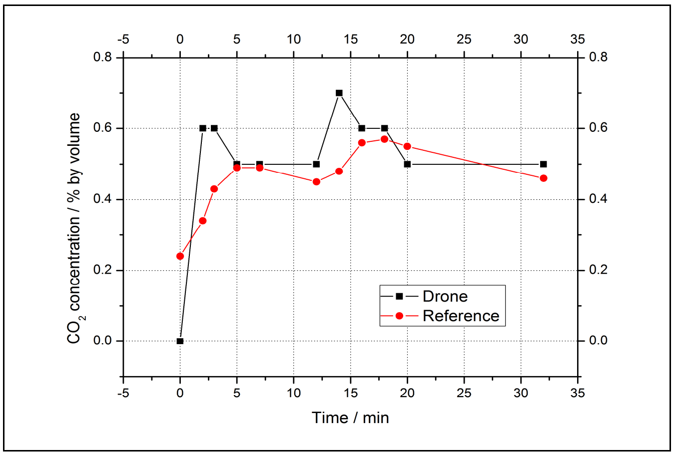

Fig. 2. Comparison of the measured CO_2 concentration at the drone and a reference device vs. time (the drone was in the air before the experiment started)

[2] The time needed to achieve a homogeneous concentration in the test chamber.

4 Field Test: Gas Measurement in a Volcanic Crater

To validate and optimize the system for real-world application scenarios, a field test was carried out in the harsh conditions of a volcanic crater (Fig. 3). Area of operation was one of the craters of the Timanfaya National Park on the Canarian Island Lanzarote. Despite being inactive, gas emission was assumed at the bottom of the volcano. Lichen growing there showed in some areas different colour, what could be an indicator for a gas impact. Wind and rocky terrain as well as the distance between micro-drone and pilot contributed to challenging operation conditions. The experiments objective was to fly down to the bottom of the crater, land at the area of discoloured lichen, perform regular gas measurements during the whole mission and return to the starting point. All operation should be carried out via remote control and the sensing data should be transmitted and displayed in real time.

Fig. 3. Field test in the Timanfaya National Park (Lanzarote, Canarian Islands)

The experiment was performed successfully. During two consecutive flights the navigation and data transmission worked well and proved the capability of the system to operate in real-world conditions. The received remote sensing data showed low concentrations of SO_2, a typical volcanic gas, which probably is the reason for the discoloured lichen. SO_2 was detected also in other areas of the Timanfaya region. Beside the gas measurement data also GPS and altitude information have been transmitted as well as a video stream during the flight.

5 Conclusion

The combination of a UAV and a mobile and flexible gas measuring device creates new possibilities to estimate the risk potential of different scenarios without endangering people. The received results of development and validation experiments demonstrate the applicability of the system. Targeted fields of operation are gas measurements in accident scenarios, emission control as

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well as data mapping and monitoring of critical areas. In a further step aerial-based plume tracking and mapping should be accomplished by calculating the wind vector from flight control data. Therefore existing plume tracking algorithms should be evaluated in simulations and experiments regarding their adaptability and optimized for this area of application.

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References:

[1] Kowadlo, G.; Russell, R. A.: Robot Odor Localization: A Taxonomy and Survey. *Int. J. Rob. Res.* Vol. 27, Nr. 8, 2008, pp. 869–894.

[2] Warburton, P. Richard; Pagano, Marcus P.; Hoover, Robert; Logman, Michael; Crytzer, Kurtis; Warburton, Yi Jin: Amperometric Gas Sensor Response Times. *Analytical Chemistry* Vol. 70, No. 5, 1998, pp. 998-1006

[3] Grewal, Mohinder S.; Weill, Lawrence R.; Andrews, Angus P.: Global Positioning Systems, *Inertial Navigation, and Integration (Second Edition)*. John Wiley & Sons, Inc., 2007