

A CONCEPT FOR AN AERIAL BASED LANDFILL MONITORING SYSTEM

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1. Introduction

The paper at hand introduces a functional UAV for mobile robot olfaction tasks, namely gas source localization and gas distribution mapping. The remote gas sensing unit is a newly developed lightweight Tunable Diode Laser Absorption Spectroscopy (TDLAS) sensor, attached to a gimbal with three degrees of freedom (DOF), which enables the UAV to perform plume reconstruction and localization of gas sources. The systems software is based on the Robot Operating System (ROS).

2. Background

Methane (CH_4) is a colorless and odorless gas, which is extremely flammable and forms an explosive mixture with air at concentration levels from 5%_{vol} to 15%_{vol}. For instance, it is generated at landfill sites by decomposition of organic waste.

To measure CH_4 in industrial areas or on landfills ground-based as well as aerial solutions are researched. Also the deployed sensing units vary from in-situ sensors like metal oxide (MOX) sensors to TDLAS sensors [1]. The latter measure the integral concentration along a laser beam. Based on the absorption along the path, the concentration of a certain gas can be calculated. The laser has to be restricted to a small range of wavelengths, to make them less susceptible to other molecules, changing temperatures or humidity [2].

The gas sensor will be attached to a proprietary developed gimbal, using sensor fusion to control its orientation. Experiments with proprietary gimbal solutions already showed satisfactory results but also show potential for further improvement [3].

3. Gas Sensing Unit

The gas sensing TDLAS being in development will be able to measure as few as 1 ppm · m at a rate of 10 Hz. The measurement light is emitted

with a wavelength near of 1653 nm. In order to calculate the integral concentration along the path of the beam the sensor uses the Beer-Lambert-Law. Its computed data is transmitted via I²C bus.

4. System Setup and Kinematics

The whole system in general consists of a UAV platform, an attached gimbal carrying inter alia the TDLAS sensor, and at least one computing unit. The whole system weighs less than 3.6 kg.

As the central computing unit an Intel[®] Joule is deployed, providing sufficient computing power, GPIOs, UART, and I²C.

The currently used aerial platform is manufactured by DJI. The onboard computing unit is able to communicate with a SDK provided by DJI in order to control the UAV, i.e. pilot waypoints or receive flight data. The latter includes the UAVs position, measured via GPS, as well as its orientation, measured by an inertial measurement unit (IMU). Both, the UAV's flight controller and the Intel compute module, are connected via UART.

The gimbal is independent of the aerial platform. To allow for compensating all three DOF of the UAV, the gimbal also has three DOF. It carries the TDLAS Sensor, a Lidar Sensor for distance measurements, an IMU, and a lightweight USB 3.0 camera, which is able to capture UXGA Videos with up to 40 fps. The camera is used for visual servoing. The control algorithms take the gimbal's absolute position into account, which is measured by merging IMU and visual odometry data. By combining these information with the flight data and the distance measurements of the lidar sensor, a precise description of the measurement is possible.

To avoid a gimbal lock, the orientation of both the UAV and the gimbal are defined as unit quaternions $\|\mathbf{q}\| = 1$. The control algorithms are consequently based on quaternion rates. The gimbals speed control is programmed using the spherical linear interpolation (SLERP) algorithm

[4]. The autonomous navigation or gimbal control is thus computed through forward kinematics, starting from a point of interest in the ground coordinate frame (see figure 1).

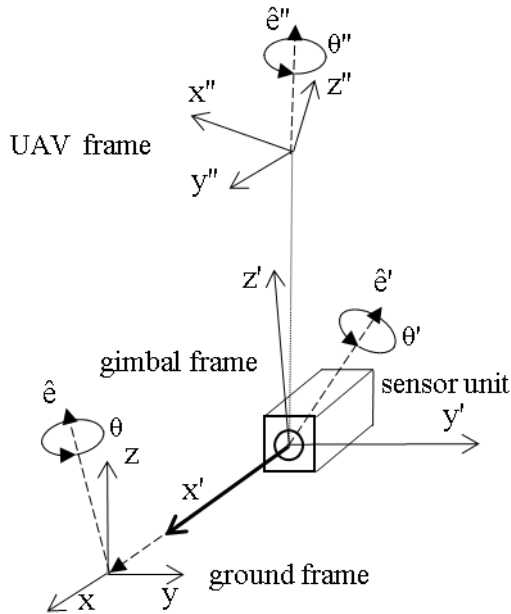


Fig. 1. The sensor orientation characterized by the UAV's orientation and its initial coordinate system

The lidar sensor mentioned before is furthermore used to perform simultaneous localization and mapping (SLAM). The odometry data is composed by estimating the UAV's position and orientation as well as the gimbal's orientation.

The UAV is controlled via a groundstation, where the missions are planned and all collected data is evaluated. Missions consist of waypoints as well as sensing procedures, including i.a. the gimbal's orientation. Since algorithms for tomographic plume reconstruction are computationally intense, these calculations are executed by the groundstation. Based on these results, missions can be planned autonomously and online.

5. Experiments

The experiments will take place at the BAM Test Site (BAM-TTS). Several different scenarios are to be carried out, including fan based gas discharging and visual ground truth motion.

The aim by using the latter is to measure the error in the UAV's pose and consequently the deviation in the ground frame. Therefore, the UAV

measures predefined points of interest from different given waypoints while being recorded. In the post processing, the pose error can be computed by merging the UAV's position, orientation, and camera data.

Furthermore, the TDLAS sensor is validated by measuring concentrations of gas from different angles, positions, and against different ground surfaces.

6. Evaluation

First experiments prove the ability to fly the drone autonomously and incorporate different sensor data. The sensor can be pointed at arbitrary spots with satisfyingly precision by manipulating the UAV's and the gimbal's orientation and position.

Detailed results of all experiments will be part of the conference presentation.

7. Conclusions

The lightweight aerial platform constitutes an enhancement in safely measuring CH_4 concentrations. The implemented autonomous routines of the UAV are assisting the pilot while performing the measurement flights.

References

- [1] Bonow, G., Kroll, A., Gas leak localization in industrial environments using a TDLAS-based remote gas sensor and autonomous mobile robot with the Tri-Max method. In: Robotics and Automation (ICRA), 2013 IEEE International Conference on. IEEE, 2013. pp. 987-992
- [2] Bergamaschi, P.; Harris, Geoffrey W. Measurements of stable isotope ratios ($^{13}\text{CH}_4/^{12}\text{CH}_4$) in landfill methane using a tunable diode laser absorption spectrometer (TDLAS). *Global Biogeochemical Cycles*, 1995, 9. Jg., nr. 4, pp. 439-447. 1995.
- [3] Neumann, P. P., et al., Bringing Mobile Robot Olfaction to the Next Dimension – UAV-based Remote Sensing of Gas Clouds and Source Localization. In 2017 IEEE International Conference on Robotics and Automation (ICRA), Singapore, 2017.



- [4] Diebel, J., Representing attitude: Euler angles, unit quaternions, and rotation vectors, Matrix, 2006, nr. 15-16, p.1-35.