ASSESSING CARGO SHIP EXHAUST EMISSIONS USING LOW-COST MULTICOPTER UNMANNED AERIAL VEHICLES

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INTRODUCTION

Ships transport more than 10 billion metric tons of cargo each year. Almost all of these ships run on fossil fuels causing high levels of pollutant exhaust emissions such as sulfur dioxide, nitrogen oxide and particulate, in addition to carbon monoxide, carbon dioxide, and hydrocarbons, which again leads to the formation of aerosols and secondary chemicals reactions recognized by EPA as responsible for adverse human health effects. Particle Matter [PM] is a mixture of heavy metals, black carbon, polycyclic aromatic hydrocarbons, and other substances suspended in the atmosphere (Bell et al., 2011) and research shows that its source in the atmosphere is mainly anthropogenic. PM differ in diameter and, consequently, in the ability to penetrate the respiratory system. Below 10 micrometers [PM10] particles can be inhaled, and selectively retained by bronchioles [PM 2.5] and villi along the airways. Despite the fact that the spotlight has been on ship exhaust emissions' characterization, few studies investigated the use of environmental drones [E-Drones] as a monitoring technique. Commercially available low-cost Multicopter Unmanned Aerial Vehicles [UAV] can be attached to a particle collection system [PCS], operated on board, *for in situ* measurement of aerosol particles in the atmospheric boundary layer [ABL].

OBJECTIVES

- developing a PCS to couple to a commercially available UAV that allows air particles sampling and characterization in Harbors;
- assessing the effectiveness of E-Drones in monitoring cargo ships Diesel exhaust, comparing with conventional sampling methods;
- developing a cost-benefit analysis regarding the E-Drone prototype developed by the authors when compared to conventional methods.

METHODOLOGY

Sampling area characterization

Leixões Harbor is located in the North of Portugal, northwest of the Iberian Peninsula, about 2.5 Miles north of the mouth of the River Douro and near the city of Porto [41.18685,-8.70240]. It is the second largest artificial harbor in Portugal, handling around 20 million tons of goods per year and represents 20% of Portuguese Foreign Trade by sea. Around 2 700 ships pass through here a year, more than 670 thousand TEU's and all types of cargo. It also receives passengers from cruise ships.

Prototype description

1. Multicopter UAV

The Phantom 4 Advanced UAV selected for the research comes with a 5-hour battery life remote controller, a built-in screen and a camera [1-in 20 MP sensor], allowing aerial videos and photos with a maximum video transmission range of 7 km. This UAV have a dual-band satellite positioning [GPS and GLONASS]. The Phantom's battery for regular flight operations has a durability of 30 minutes. However, the experimental flights revealed that the maximum duration of each flight is approximately 15 minutes due to meteorological conditions and to the introduction of the PCS, which changed the weight of the equipment.

2. Mass flow sensor

A reliable determination of air particles concentration requires the precise determination of the sampled air volume. This was achieved by installing a mass flow sensor that permanently remains in the airflow path of the PCS, irrespective of whether data from the flow sensor is collected or not. The SFM3000/ CMOSens® sensor is a digital flow meter operating from a 5 Volt supply voltage and features a digital 2-wire C interface. The sensor combines signal processing and digital calibration on a single microchip. This sensor can measure up to 200 L per minute.

3. Batteries

The PCS prototype will make use of Turnigy Nano-tech batteries [Li-Po; 950mAh; 7,4V] that allows the UAV to operate with a safety margin of one hour. The battery will provide power to the blower, so it can make the environment monitoring.

4. Blower

The blower, powered by the batteries, is responsible for the extraction of the air. The electrically operated blower must ensure a high airflow volume through the PCS during flight operations, providing a 5 L per minute of mass flow. Blowers, which are more powerful, but bigger and heavier, could disturb the drone and require also larger and heavier batteries. Given the charge limit admitted for this UAV, it was not viable for the research. The blower used in the prototype was taken from a mini vacuum cleaner, commercially available.

5. Microcontroller and NPN Transistor [Semiconductor]

The ESP32 microcontroller selected for this research is responsible for reading the sensor, generating the engine control signal and communicating via Wi-Fi with a mobile phone. In this way, air extraction is controlled at each altitude. The prototype uses a NPN transistor in a TO-92 package, being responsible for switching and Amplify-and-Forward relaying.

6. Air inlet

The geometry and orientation of the air inlet must guarantee that the sampled air is representative in terms of its particle load. This can be achieved by isokinetic sampling [Kulkarni et al., 2011], meaning that the flow velocity of the air entering the inlet is identical, by magnitude and direction, to the flow velocity of the surrounding air approaching the inlet. If isokinetic sampling is not ensured, aerodynamic effects, such as particle mass inertia and coefficient of drag, can result in a no representative surrounding air uptake and biased particle concentration value. The larger the particles, the higher the mass and thus inertia, the more important isokinetic sampling becomes [Kulkarni et al., 2011]. In order to provide omnidirectional air intake under isokinetic or at least near-isokinetic conditions, a bell-mouth shape air inlet was chosen.

7. Particle extraction unit

In order to allow short sampling operation periods, the prototype includes a particle extraction unit. In order to achieve a lean workflow from sampling to visual particle identification and counting, the extracted particles should be easily accessible for visual analysis without complex and time-consuming sample preparation steps. An impactor has the potential to meet all these demands. The functional principle of an impactor is based on the deflection of a particle-loaded free-flow gas stream by means of an impaction plate [Kulkarni et al., 2011], coated with a filter in the open jet at a small distance from the nozzle. This forces the particle-loaded gas stream to deflect. Due to their mass inertia, the particles in the gas stream are able to follow this deflection only to a limited extent. Therefore, particles with a sufficiently high mass inertia impinge on the surface of the impaction plate and are retained in the filter.

8. Portable Total Particle Suspended Sampler

The prototype uses an L-30/ Rotheroe & Mitchell Portable Total Particle Suspended Sampler with a sampling flow rate of 36 L/min. The collection of atmospheric particles will be carried out in 60 mm diameter quartz filters [QM-A, Whatman], previously burned at 500ºC for 12 hours. The filters will be weighed before and after sampling, and after conditioning for 24 hours, at room temperature and 50% relative humidity. The concentration of total suspended particles will be determined gravimetrically, based on the mass of particles deposited on the filters and the volume of air that passed through the filter during the sampling period.

DRONE RESTRICTIONS

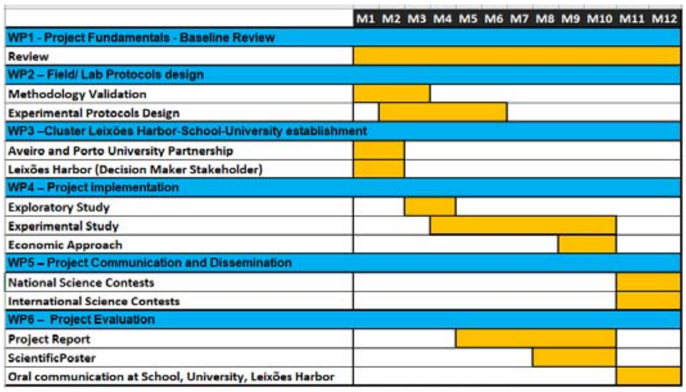
According to the Portuguese Civil Aviation Authority [ANAC], the UAV flight height allowed for the research area is 30 meters above the ground.

PROTOTYPE DEVELOPING COSTS

- UAV – preexisting. Rent 30 EUR/month*12 months - 360 EUR
- Blower - 22,30 EUR
- Batteries - 13,40 EUR
- Mass flow sensor- 88,06 EUR
- ESP32 microcontroller – 15 EUR
- Quartz filters – 170 EUR
- Petri Dishes – 173 EUR
- 3D Printing – [5EUR/hour+0.5 EUR/ml] – 140 EUR

Total**: 981,76 EUR**

PROJECT TIMELINE/ TEAM TASKS



Team Tasks

João Cunha – Economic analysis; Mariana Gonçalves – Research; Miguel Noites – Mechanical prototyping; Pedro Dinis – Electronics.

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