Use of Drones for Air Quality Monitoring

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***Abstract* — This work describes the experimental results of an hexacopter for air quality monitoring capable of flying at altitudes up to 5000 meters above sea level (MASL) at challenging weather conditions (low air density, strong winds and low temperatures). The drone is equipped with sensing technology to monitor the air quality. The flight performance of the multicopter at high altitudes and the air quality monitoring system were tested in different scenarios. This work presents the comparison of electric and aerial data of the hexacopter's flights in different locations in Peru: Ticlio (4800 MASL), located 5 hours away from Lima, Antamina mine site (4300 MASL) located 4 hours away from Huaraz, Lima (sea level); and the comparison of air contamination data from the low-cost air quality sensing system of the drone versus professional equipment certified by EPA (Environmental Protection Agency of United States) that belongs to SENAMHI, the governmental environmental agency of Peru.**

***Keywords*-—Unmanned Aerial Vehicles, Hexacopter, High Altitude, Air Quality, Contamination Monitoring.**

I. EXPERIMENTATION AND TESTING

A. Testing at high altitudes

The experiments were performed at three different locations with different pressure altitudes. Table 1 compares the pressure altitude of each location and the setup. Propellers with different sizes of diameter and pitch were used depending on the altitude and atmospheric pressure. The scenario with the lowest atmospheric pressure was the most challenging for the equipment.

The field experiments were designed to test the hexacopter at high altitude scenarios and study its performance to improve the design and components selection for industrial applications at high altitudes. Table 2 shows the geographical altitude above sea level (ASL) of the location measured by the hexacopter's GPS, the flight altitude above ground level (AGL) and the atmospheric pressure. Another important parameter to measure during flight is the battery current consumption because it is directly related to the flight time of the hexacopter. Table 3 summarized the results.

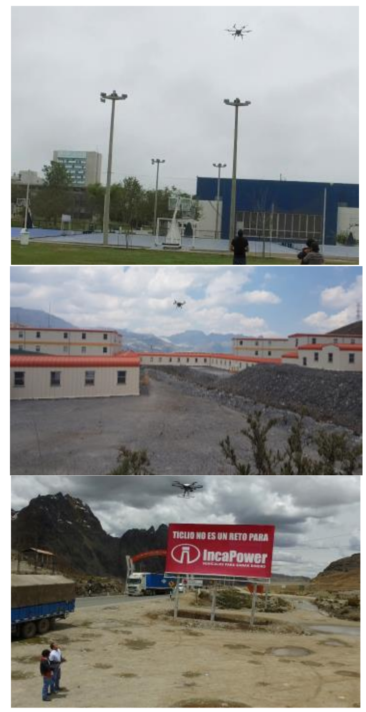

Fig. 1. Flight tests at [Up] PUCP campus, [Middle] Antamina mine site, [Down] Ticlio.

TABLE 1
FLIGHT TEST SCENARIOS

Location	Pressure Altitude	Setup
PUCP	60m	17' propellers
Antamina	4300m	18' propellers
Ticlio	4800m	18' propellers

TABLE 2
FLIGHT PARAMETERS RECORDED BY AUTOPILOT

Location	GPS Altitude (ASL)	Atmospheric Pressure (milibar)	Temp. (°C)	Flight Altitude (AGL)
PUCP	87m	1006	21	48m
Antamina	4277m	616.2	29	45m
Ticlio	4818m	554.8	10	10

TABLE 3
RESULTS FOR FLIGHT TEST CURRENT CONSUMPTION

Location	Propeller (inch)	Mean Current Consumption (A)	Flight Time (min)
PUCP	17 x 5.8	24.17	30
Antamina	18 x 6.1	35.09	22
Ticlio	18 x 6.1	45.12	18

TABLE 4
COMPARISON OF THEORY AND EXPERIMENTS

Location	Theoretical Current Consumption (A)	Real Current Consumption (A)	Theoretical Flight Time (min)	Real Flight Time (min)
PUCP	30.6	24.17	24.3	30
Antamina	47.3	35.09	19	22
Ticlio	50.2	45.12	15	18

The current consumption in Lima is the base line. According to Table 3, the current consumption increased 87% from the PUCP flight site to Ticlio one. It is noticeable that the change to larger propellers lowers the current consumption of the battery, which means that the flight time could be increased. Fig. 1. shows images taken when performing tests in the different sites.

Comparing the theoretical and experimental results is important; the results show that the real current consumption is lower in average by 20% approximately, which means that the real flight time will increase as shown in Table 4. It is demonstrated that the theoretical values are an adequate approach to evaluate the performance in real scenarios.

B. *Testing of air quality monitoring system*

This drone is equipped with low-cost sensors for air quality ($200 - $1500 per sensor) which are light weight for use on drones. Its measurements are compared to EPA gas analyzers ($15,000 - $25,000 per analyzer) located in the station of SENAMHI in the district of "Puente Piedra" - Lima.

The main objective of the comparison of the measurements from both systems is the validation of the use of the low-cost sensor in this application by identifying the correlation, mean error and percental error. In an ideal scenario, the correlation would be above 0.9 and the error below 20%, which would comply with the category Tier III – Supplementary Monitoring Network of EPA.

The system uses electrochemical sensors for gases and light sensor (Mie theory) for particulate. All of the sensors that will be used on the drone (carbon dioxide - CO2, particulate matter - PM2.5, PM10, sulfur dioxide - SO2, nitrogen dioxide - NO2, nitrogen oxide - NO, carbon monoxide - CO), were allocated in a separate housing, which was also equipped with sensors for temperature and relative humidity since both parameters affect the readings of electrochemical sensors. The system was supplied from the power grid (220VAC, 60Hz) and was located near the intake of the station in order to measure the same air. Fig. 2. Shows the setup. The measurements in parallel were performed for 19 continuous days, and sampled every 0.5s. Comparisons between measurements are analyzed in Table 5.

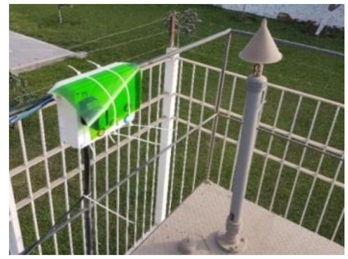

Fig. 2. Sensor setup for experiment. The drone sensors must be near the air intake to establish a valid comparison.

TABLE 5
COMPARISON OF MEASURED DATA

	Correlation	Mean error (ppb)	Mean percental error (%)
CO	0.62	144.82	25.22
NO	0.64	7.64	48.44
NO2	0.13	4.12	20.22
SO2	0.53	1.30	49.51

For gases NO2 and SO2, the results of the low-cost sensors are not optimal because the correlation values are low (below 0.6) and the percental error is high (above 20%). The main reason is that the real values of concentration of these gases in the air were very low (near to 0ppb), and the sensors are not sensitive enough to detect such low values. In the case of gases CO and NO, the results of low-cost sensors are more encouraging, the correlation values are high (above 0.6). This better performance was due to the fact that the concentration of these gases in the air was higher (above 10ppb), which the sensors were able to monitor.

II. GOALS AND IMPACT

The main objective of this project was to perform field tests of air quality monitoring with the drones previously designed and built, and validate this solution in high-altitude and contaminated areas such as Ticlio (4800 MASL) in Peru.

The goals achieved during this project were the following:

- Flight tests of the drone in 3 different scenarios and climate conditions: Lima (sea level), Antamina mine site (4300 MASL), Ticlio (4800 MASL).
- Workshop in a high-potential site for air monitoring, Madre de Dios in the jungle of Peru, for communication to the citizens and authorities about the project.
- Presentation of poster in IEEE International Conference on Robotics and Automation (ICRA 2018).
- Publication of results in webpage "IEEE RAS-SIGHT".

With the drone for air quality monitoring, we want to achieve social and environmental impact: pollution control in mining areas in Peru and its surrounding populations through the measurement of contaminating gases and dust; increase air quality monitoring in urban areas; create awareness about the quality of the air people breathe and its effects on health.

The funding from RAS-SIGHT was valuable to prove the technology on site, in difficult climate conditions in high-altitude areas; compare its performance with normal weather conditions (at sea level); validate the air measurement technology on the drone; and communicate the benefits of the project to the local communities where this technology could be deployed for pollution monitoring.

III. CONCLUSION AND FUTURE WORK

In this project, the contribution of the developed hexacopter to the current state of the art lies in the evaluation of the technical aspects related to power efficiency in high altitude environments for industrial applications.

The low-cost air quality sensors show a solid performance when compared to certified and expensive equipment. A correction algorithm will be applied to perform more measurements.

Our results are encouraging and show that the rotor system is a key component to improve the current consumption of the motors at high altitudes. More test flights will be performed at high altitudes to gather more data on UAV behavior at harsh environments for industrial applications. Industries in Peru such as mining, oil, electric are looking forward to the development of robust aerial systems that can withstand the harsh conditions of their operation sites in order to improve their normal processes for air quality monitoring.

The tests on site with potential users of the technology contributed to the development of the second version of the drone for air quality monitoring which is shown in Figure 3, and a static module for air quality monitoring with is shown in Figure 4. Both of these technologies are currently used by governmental agencies for air pollution measurement in real-life scenarios.

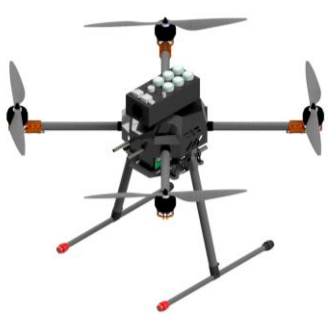

Fig. 3. Second version of drone for air quality monitoring

Fig. 4. Static module for air quality monitoring

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