Developing a Modular Unmanned Aerial Vehicle (UAV) Platform for Air Pollution Profiling and Emergency Monitoring

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Specific Aims

Many people living in or near large cities are subject to poor air quality, which has been identified as a leading risk factor for global disease burden.[1,2] Metropolitan cities like Memphis are among the top ten most polluted in the USA with respect to particulate matter and ozone. The current monitoring capacity is insufficient for reliable evaluation of public health risk, identifying emission sources, or implementing effective pollution control strategies.[3] New technologies such as low cost commercial micro-sensors that interface with the off-the-shelf micro-controller systems offer the ability to measure important air pollutants with high sensitivity and temporal resolution. Similarly the availability of unmanned aerial vehicles (UAVs) or "drones" for commercial and recreational use now exists at costs that make them more accessible to the average user. The applications of UAVs in air pollution are still limited given the short history of low-cost UAVs and sensors, warranting the need to develop reliable UAV platforms for air pollution monitoring.

The overall objective of this study is to develop a modular unmanned aerial vehicle (UAV) platform and demonstrate its applications in air pollution profiling and emergency monitoring. There are two specific aims:

Aim 1: Develop a modular unmanned aerial vehicle (UAV) platform capable of real-time monitoring multiple air pollutants. This UAV platform will feature: (1) a stable, high precision X-Y-Z platform, for air sample collection; (2) capability of monitoring multiple air pollutants with a modular design and next generation lightweight sensors; (3) real-time data collection, links, and imaging; (4) flight on pre-determined pathways; (5) adequate flight time for various integrated and time series data collection missions; and (6) autonomous methods for sample collection.

Aim 2: Demonstrate the applications of this UAV platform in air pollution research, focusing on roadside air pollution profiling and emergency monitoring for air pollution episodes.

The principal investigator Dr. Chunrong Jia has conducted a series of air pollution studies in the Memphis area (www.memphisair.org), and has built an air monitoring laboratory with multiple state-of-the-art instruments. The co-investigator Dr. Qijun Gu is an expert in cyber-physical systems and has long experience in technology development and commercialization. Thus, the long-term goals for this project are to: (1) Build on Dr. Jia's ongoing efforts to establish an air pollution exposure research hub in the Great Memphis Area. (2) Commercialize cost effective modular UAV air monitors that can be utilized by government agencies, research institutions, and community partners.

Justification for Research

Need for air pollution data with high spatial and temporal resolution

Exposure to air toxics in metropolitan areas may be of significant health concern because populations and emission sources are concentrated in the same geographic area.[4] There is a critical need to enhance air pollution monitoring in order to more realistically evaluate of public health risk and setting of standards;[3] however, current monitoring capacity is challenged by the decreasing air concentrations and continuing need for high temporal and spatial resolution data. Centrally located sampling sites do not reflect outdoor residential (backyard) levels,[5] and monitoring data are scarce, forcing a reliance on emission measurements and model predictions that tend to bias levels of urban air pollution.[6] Modeling provides only screening level predictions, which do not capture known temporal and spatial variation[7]. Further, vertical atmospheric measurements are in critical need for air pollution forecasting and evaluation, in particular, in megacities with high rise buildings. Capturing the spatial and temporal variability of aerosol particles and trace gases between the surface and 300m is currently limited by the sampling platforms with which routine measurements can be made. This situation significantly limits the understanding and impedes the management of air pollution, and brings increasing need for on-site fast analysis of field samples. Mobile, real-time instruments equipped with new technologies offer numerous advantages for capturing the spatial and temporal variability of air pollutants.[8] In particular, we have identified two priority areas that are in high need of UAV air monitoring platforms.

Need for near road air monitoring. The transport sector remains the largest emitter of NO_2 in the US and and mobile sources are major sources of other pollutants including fine particulate matter (PM2.5) and VOCs.[9] EPA requires near-road monitoring of NO_2 is in larger metropolitan areas to support the revised National Ambient Air Quality Standard (NAAQS).[10] These areas include 102 Core Based Statistical Areas (CBSAs) with populations over 500,000, which include Memphis. While the number of scientific investigations on trafficrelated air pollutants is increasing, data for exposure assessment purposes are still not abundant; the data gap in developing countries is particularly large.[11] Thus, there is a clear need for methods and data to better assess air pollution exposures from traffic sources, and to reduce the spatial and temporal errors in exposure estimates for subjects in epidemiologic and other studies.[12-14]

Need for emergency response monitoring. When environmental disasters take place, local communities and health care providers need information fast – they need to know what's in the air, how high the levels are, and what to do to protect people's health. There are major deficiencies in the collection of information needed to rapidly assess health risks and inform the public after environmental emergencies and/or disasters occur, mainly these are (1) inadequate and outdated monitoring equipment; and (2) regional disparities in monitoring capabilities resulting in delayed or missing data.[15]

UAVs for air monitoring and meteorological measurements

The UAV has been an attractive experimental platform for high-spatial-resolution, near-surface vertical profiling of atmospheric pollution in recent years.[16,17] Previous technologies used balloons,[18] aircrafts,[19] and satellite remote sensing,[20,21] which are unmaneuverable or expensive. Recent advancements in quadrotor UAV technology present an attractive, low-cost alternative for sampling the lower troposphere due to their ability to translate in both the horizontal and vertical dimensions and to hold a fixed position in the atmosphere even under high-wind conditions. Still, even an extensive literature review only identified a small number of air pollution studies that utilized UAVs.[22] Despite the most use for meteorological measurements,[23] UAVs have been used to measure air pollutants with a focus on particulate matters.[24-28] Other applications include carbon dioxide,[29,30] methan,[31,32] and ozone.[33] This relatively small number of papers implies that the field is still in its early stages of development.[22]

Challenges in UAVs for air monitoring

While the potential of UAVs for air quality research has been promising, challenges still need to be addressed. These challenges are not only technological, but policy and regulations. Significant gaps also exist in the realworld monitoring and comparisons with the reference methods.

(1) Energy efficiency and flight time. A typical consumer drone in the price range of $500 to $2000 can fly for about 15 minutes to 30 minutes on one fully charged battery. Carrying the platform will reduce the drone flight time, because the platform adds weight to the drone and the platform itself consumes electricity. A typical USB-powered micro-controller device consumes the power in the range of 1W to 10W. Hence, there is a large power consumption space for us to study and find an optimal design with hardware and software to reduce the weight and the energy consumption of the platform.
(2) Synchronization of monitoring sensor data and GPS data. For real-time monitoring and geo-spatial data modeling, we need to synchronize air pollution data and GPS data, because they come from the air pollution sensor and the drone separately. The internal clocks of the sensor and the drone are not synchronized at all. Worse, they do not have built-in ability to implement network timing protocols. Rather than synchronizing the devices, we will study and develop mechanisms to produce synchronized data within an error tolerance.
(3) Multiple air pollutants. Air pollutants are present as mixtures in all the air environments, Both the scientific community and regulatory agencies have been shifting from the traditional single-pollutant approach toward a multipollutant approach to quantify the health consequences of air pollution mixtures.[34] Current applications mostly focus on particles, ignoring many other pollutants of concern, e.g., volatile organic compounds (VOCs).

(4) Regulations and restrictions. Importantly, unmanned aircraft cannot be deployed without restrictions. Under current aviation safety operating regulations, restrictions are placed on their use in commercial, research and private applications.[35]

(5) Planned flight path. The drone's flight path must be planned and aligned with the need to geo-spatial data profiling and modeling. It is challenging to create an optimal flight plan under a variety of constraints. Since drone's flight time is limited, we need to plan an optimal flight path so that we can collect sufficient data along the path to build geo-spatial modeling of air pollution around the area of interests. Meanwhile, we need to consider other factors in the flight plan. For example, we need to include GeoFencing into the flight plan to avoid no fly zones.

(6) Validity of sensors. The evolution of low cost sensors has resulted in a number of such instruments becoming commercially available. However, they are often not validated before the real monitoring, and some experiments have found significant disagreements with reference methods.[36] Thus, the performance of miniature sensors need frequent calibrations and comparisons.