Development of an Autonomous Unmanned Aerial System for Atmospheric Data Collection and Research

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ABSTRACT

This paper addresses the use of unmanned aerial systems (UAS) to carry out atmospheric data collection and studies. An important area of research is the study of the chemistry and physics of Earth's planetary boundary layer (PBL). The PBL, also known as the atmospheric boundary layer (ABL), is the lowest part of the atmosphere and its behavior is directly influenced by its contact with the planetary surface. Sampling of the PBL is performed in a timely and periodic manner. Currently, sensors and uncontrollable balloons are used to obtain relevant data and information. This method is cumbersome and can be ineffective in obtaining consistent environmental data. This paper proposes the use of autonomous UAS' to study the atmosphere in an effort to improve the efficiency and accuracy of the sampling process. The UAS setup and design is provided, and preliminary data collection information is shared.

Keywords: Unmanned aerial systems, atmospheric studies, data collection.

1. A BRIEF INTRODUCTION

This paper addresses the use of autonomous unmanned aerial systems (UAS') or vehicles (UAVs) to carry out atmospheric sampling in areas of geographical and environmental importance. Atmospheric sampling entails collecting measurements (e.g., wind speed, temperature, humidity, pressure, carbon monoxide) in the air used to study atmosphere structures and dynamics. Furthermore, this information may be used for weather prediction, impacts of pollution on the environment, and the effects of climate change. This is an emerging field with significance to a number of research teams and U.S. government agencies, including NOAA, NASA, and the USDA. The Joint Center for Earth Systems Technology (JCET) at UMBC is interested in the development of new technology for remote sensing [1]. An important area of research for JCET and NCAS is the study of the chemistry and physics of Earth's planetary boundary layer (PBL). The PBL, also known as the atmospheric boundary layer (ABL), is the lowest part of the atmosphere and its behavior is directly influenced by its contact with the planetary surface. Sampling of the PBL is performed in a timely and periodic manner. Currently, sensors and uncontrollable balloons are used to obtain relevant data and information. This method is cumbersome and can be ineffective in obtaining consistent environmental data. Furthermore, the balloon and sensor apparatus are often lost, which significantly increases the cost of the data collection method. This paper proposes the use of autonomous UAS' to study the atmosphere in an effort to improve the efficiency and accuracy of the sampling process. The UAS' will be designed specifically for the task of atmospheric sampling, will be reusable, and will yield repeatable results. Autonomous methods and nonlinear control strategies will be developed later to improve upon the data collection and UAS efficiency.

Given the importance of data obtained from environmental samples and the difficulty of broad, frequent, manual sampling, it is not surprising that there is growing interest in robotic sampling methods [2, 3, 4]. There are a number of different sampling methods found in literature and practice. These methods typically vary by means of locomotion, degree of autonomy, and sampling mechanism [5]. All of the sampling systems studied have extremely limited autonomy. Collection locations are specified as GPS coordinates, perhaps with

GPS waypoints to aid navigation. The assumption is that the path to and between waypoints is obstacle free, as is the path down to the landing surface. In contrast, this work proposes to couple GPS with active autonomous control using visual and/or light detection and ranging (LIDAR) sensors to support obstacle avoidance en route as well as landing and hovering at suitable locations. This becomes crucial with, for example, where GPS may not be precise enough to specify a safe path of flight near a radar tower. It is proposed that new UAS' may be developed to include new nonlinear control methods and autonomous strategies for obtaining atmospheric samples. Members of the engineering and scientific community have studied and are currently studying UAS deployment for atmospheric and environmental data collection [6, 7, 8, 9, 10, 11, 12, 13, 14, 15]. Due to climate change and environmental factors, it is a rapidly growing field.

This paper is organized as follows. The proposed system for atmospheric data collection is discussed in Section 2. Preliminary data collected from a balloon flight with an RS92 sensor is shown in Section 3. It is assumed that similar data will be collected from the UAS when fully operational. Conclusions and future work are discussed in the final section of the brief paper.

2. DEVELOPMENT OF PROPOSED UAS

Brief Overview

For the proposed UAS, the hardware and software platforms will be completely open and can be used entirely or in part by others for environmental monitoring. The proposed work will be extendable beyond atmospheric sampling. Design and control optimization will increase power availability for other purposes, such as additional sensors or sampling mechanisms. The elements of autonomy related to obstacle avoidance, path planning based on waypoints, and landing site selection should be easily adaptable to other rotary-wing aircraft, thereby extending the utility of related research efforts. Multi-copter and fixed-wing UAS' can be used as test-beds for new sensors and UAS designs. The user interface for variable autonomy in which the human can specify skeletal flight plans and assist as needed for fine grained control will again serve as a multiplier for human effort, be adaptable by other researchers, and lower the barrier in terms of required expertise for participating in obtaining samples. This is critically important for scientists who are more interested in the quality of the data rather than the process of obtaining the data. Therefore, the design process of the UAS' will include end-users, and will be iterative to include feedback from the users. This work is both experimental and theoretical in nature. There is a significant amount of experimental and hands-on work. For example, the UAS and sensor suite need to be designed and constructed. Furthermore, this work is governed by theoretical developments such as optimization of the nonlinear controller and autonomous system. In addition, software development and programming is also required. The mechanical and software design of the UAS will be based on engineering guidelines and sample quality requirements. These will be determined in collaboration with environmental scientists and collaborators at the start of the project, and will be re-evaluated throughout the project duration. As such, the design process is considered to be iterative. At a fundamental level, the autonomous UAS and function is dictated by the quality of the samples obtained and used by the research scientists.

Data Collection Device

The data collection device selected for the UAS atmospheric studies is the RS92 radiosonde [16]. The RS92SGP is recognized as one of the most reputed commercial radiosonde. It has been selected by the World Meteorological Organization GRUAN project to be used for highly accurate measurements of the thermodynamic properties (temperature, relative humidity, and pressure profile) that will serve as reference to calibrate data from more spatially-comprehensive global observing systems (including satellites and current radiosonde networks). The wind speed and direction is derived from the GPS, as the balloon (or proposed UAS) is considered to be a Lagrangian reference. Table 1 shows the characteristics of the RS92SGP sensors. Data collection is done by a proprietary transceiver system, in which houses two antennas, one for the thermodynamic parameters and the other for the GPS signal. Before any launch, a ground check is performed using Vaisala's GC25 set, and an independent air pressure sensor. If there are large discrepancies between the radiosonde and the ground check measurements, the RS92 might be rejected. Following the table is a figure of the RS92 being implemented on the proposed UAS.

Table 1. RS92 Specifications

Parameter	Type	Accuracy	Response time (s)
Temperature	Capacity wire	0.5 C	0.4 (1000 hPa)
Relative Humidity	Thin film capacitor, heated twin sensor	5%	0.5
Pressure	Silicon	1 hPa	N/A
Location, Winds	GPS	10 m – horizontal 20 m – vertical 0.15 m/s – wind speed	N/A

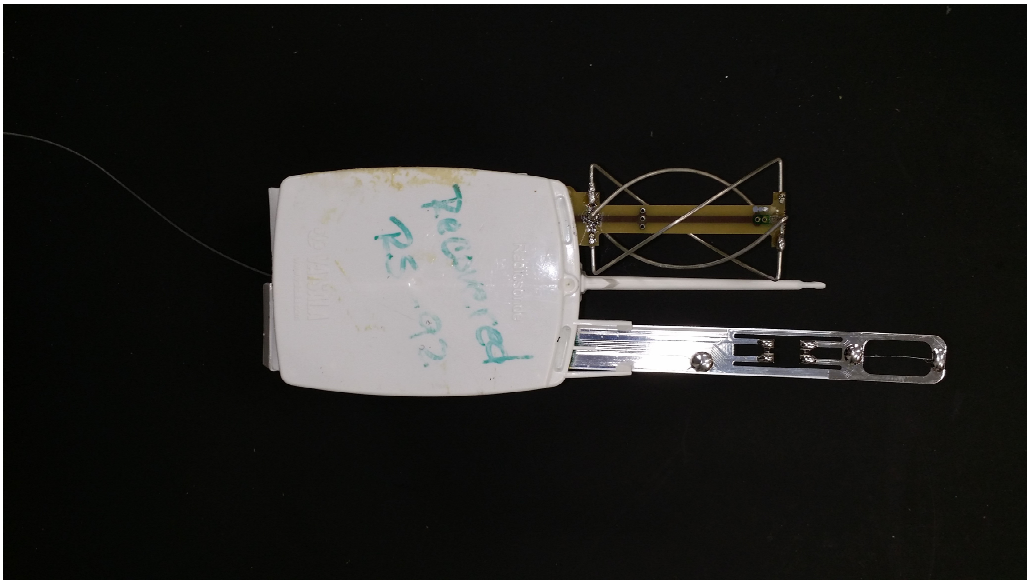

Figure 1. Picture of the RS92 device installed on the proposed UAS atmospheric data collector.

The Proposed System

For these studies, an octocopter unmanned aerial system was selected. An octocopter has eight propellers and motors that provide substantial lift and power. In addition, these systems generally can fly higher altitudes than the popular quadcopter, and are significantly more stable. The UAS selected for these studies is manufactured by MikroKopter in Germany. The model number of the UAS shown below is ARF-OktoXL. The RS92 is attached to the bottom of the octocopter. As shown in the figures, an arm mechanism was laser cut out of plexiglass. As the octocopter takes off from the ground, the arms will extend and lower the RS92 from the lower body of the octocopter. This allows the sensors to be sufficiently far away from the octocopter to minimize disruptions and other measurement noise. The deployed arm also securely attaches the RS92 such that the sensors will not be damaged by the UAS operation. In addition, the arm has been designed in such a way that minimal 'swaying' occurs during flight. This swaying (due to momentum forces of the RS92 acting on the body of the copter) could lead to unsafe operating conditions. The deployed arm collapses and folds up upon UAS landing.

Figure 2. The proposed UAS setup for collecting atmospheric samples and data.

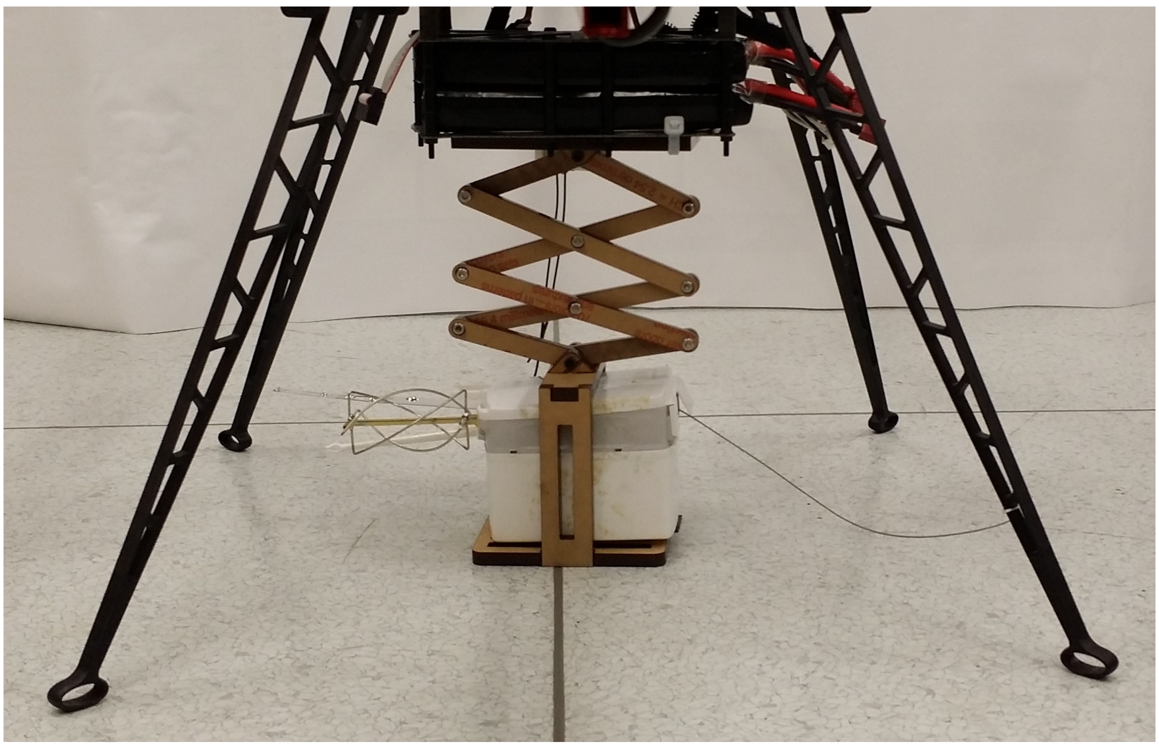

Figure 3. The deploying arm mechanism for the RS92 attached to the UAS.

3. PRELIMINARY DATA AND RESULTS

Due to restrictions and regulations, preliminary results from the actual developed UAS have not been obtained. However, preliminary data has been acquired by weather balloons flying at levels expected of the UAS. The following figures illustrate what sample data will look like from the UAS when operational. The first figure shows the latitude and longitude of a balloon flight outfitted with an RS92. The balloon is uncontrollable and often the collection of data is restricted to the wind speed and atmospheric conditions during flight. The second figure is a simple altitude (height) graph which shows the altitude change throughout the flight, with a sample taken once per second. The third figure shows the wind speed detected by the RS92. The final figure illustrates both the atmospheric temperature and percent relative humidity as a function of time. A correlation exists between the two, as expected, during the balloon flight as different atmospheric layers were encountered. An important distinction between atmospheric data collection of balloons and the proposed UAS is the operating ceiling height. The proposed UAS should only be operated under 5,000 feet, and with accordance to FAA regulations and government laws. However, at these altitudes a number of other safety factors need to be considered, including but not limited to: reliability and general health of copter, safe and controlled operation, maintained ground visibility, available power, and communications efficiency. An advantage of using an UAS when compared to a weather balloon is the controllability of data collection and sampling. For example, a very accurate 3D atmospheric model may be collected and generated throughout a region of space, rather than a linear slice of atmospheric sampling.

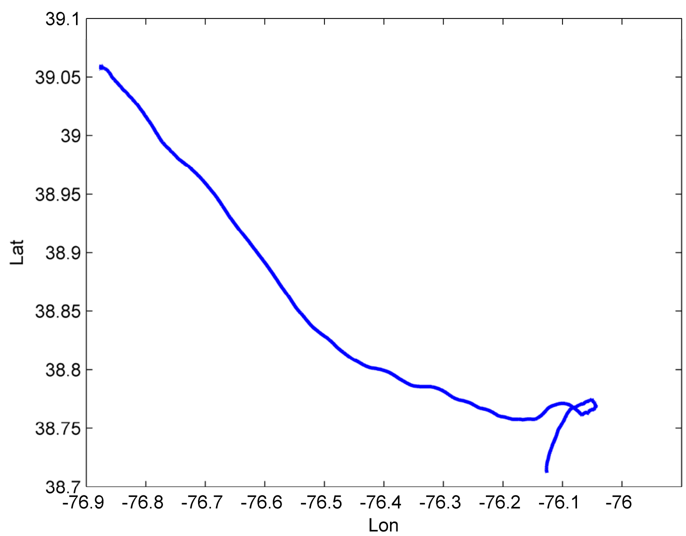

Figure 4. Latitude and longitude plot of sample balloon flight and RS-92 data collection.

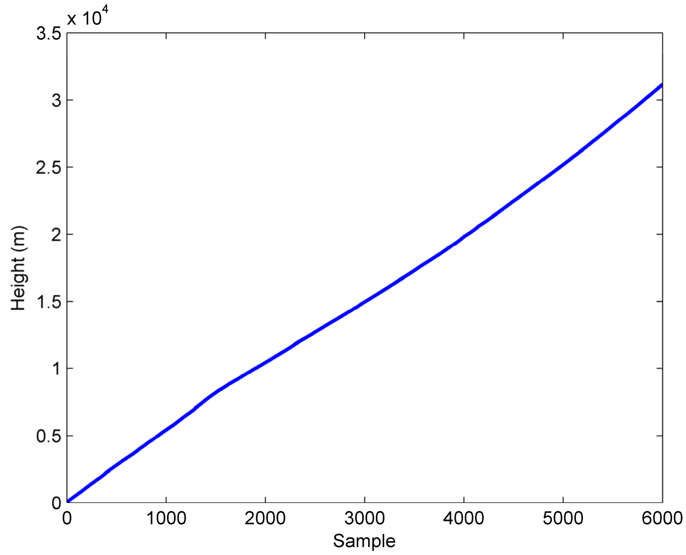

Figure 5. Altitude (or height) profile of the balloon flight with RS-92 data collection.

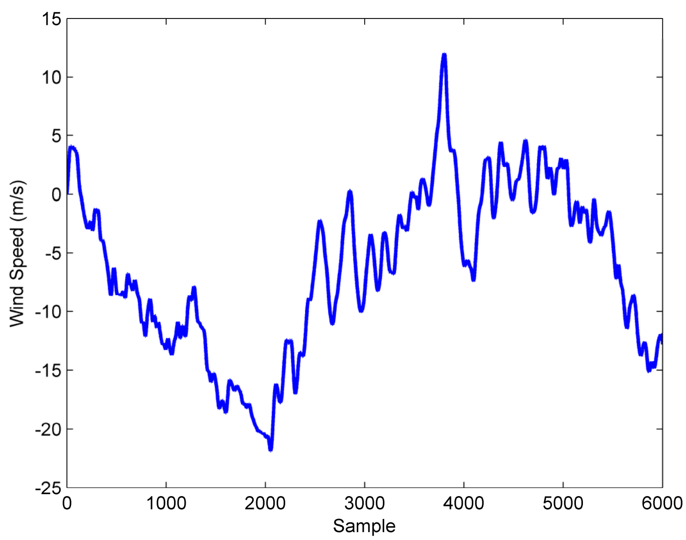

Figure 6. Wind (or relative wind) speed during balloon flight.

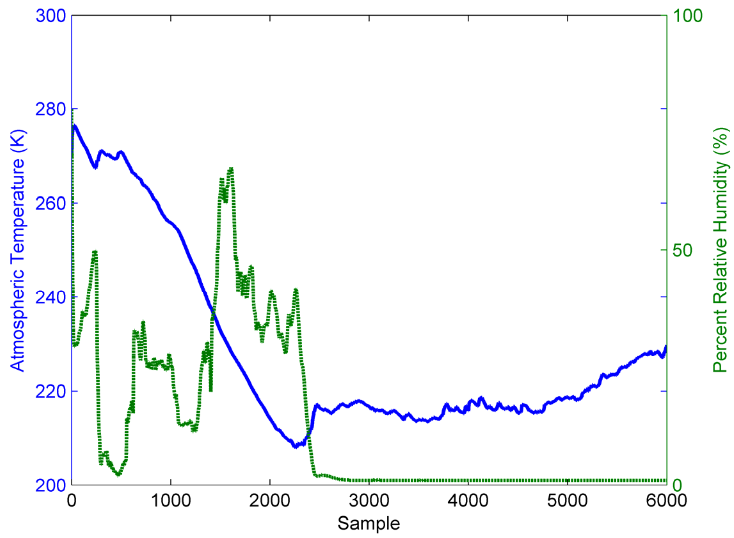

Figure 7. Atmospheric temperature and percent relative humidity during the balloon flight.

4. CONCLUSIONS AND FUTURE WORK

This paper proposed the use of unmanned aerial systems (UAS) to carry out atmospheric data collection and studies. This is an emerging field with significance to NOAA, NASA, USDA, and other government agencies. The PBL, also known as the atmospheric boundary layer (ABL), is the lowest part of the atmosphere and its behavior is directly influenced by its contact with the planetary surface. Sampling of the PBL is performed in a timely and periodic manner. Currently, sensors and uncontrollable balloons are used to obtain relevant data and information. This method is cumbersome and can be ineffective in obtaining consistent environmental data. This paper proposed the use of autonomous UAS' to study the atmosphere in an effort to improve the efficiency and accuracy of the sampling process. The proposed UAS setup and design was provided, and preliminary data collection information was shared. Future work will look at implementing this system, according to FAA rules and regulations, in an effort to compare the quality of data obtained with current practices.

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