Open Access Library Journal
2024, Volume 11, e10232
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Course Design for Low-Altitude Atmospheric Detection Experiment Based on Multi-Rotor Unmanned Aerial Vehicle

Xiaohang Wen

School of Atmospheric Sciences, Chengdu University of Information Technology, Sichuan
Email: wxh@cuit.edu.cn

How to cite this paper: Wen, X.H. (2024) Course Design for Low-Altitude Atmospheric Detection Experiment Based on Multi-Rotor Unmanned Aerial Vehicle. *Open Access Library Journal*, **11**: e10232.
http://doi.org/10.4236/oalib.1110232

Received: May 9, 2023
Accepted: February 25, 2024
Published: February 28, 2024

Abstract

The atmospheric sounding experiment is a practical course that complements the theoretical course of atmospheric detection. Mastering the basic experimental techniques of atmospheric detection is a fundamental requirement for the development of talents in atmospheric science and atmospheric detection for the new era of meteorological observation. The School of Atmospheric Sciences at the Chengdu University of Information Technology has adjusted the teaching content and system of the traditional undergraduate course "atmospheric detection experiment" by integrating teaching and laboratory resources, and established a teaching system that combines basic experiments with cut-ting-edge experiments, validation experiments, and independent design experiments, laying a foundation for improving the quality of teaching of the undergraduate course "atmospheric detection experiment". This article will focus on the design ideas, observation methods, principles, and comparison results verification of the "low-altitude atmospheric element detection experiment based on multi-rotor unmanned aerial vehicles" in the atmospheric detection experiment course. This article breaks through the traditional operation of atmospheric detection experiments, and combines modular design and practice of a new experimental course system to design novel atmospheric-sounding experiments and course systems, achieving good application results.

Subject Areas

Atmospheric Sciences

Keywords

Atmospheric Sounding Experiment, Low-Altitude Atmospheric Elements, Unmanned Aerial Vehicle Detection, Course Design

1. Introduction

Atmospheric detection is a branch of atmospheric science that involves a very wide and specific range of topics [1]. The course "Atmospheric sounding" mainly discusses the development of atmospheric detection instruments, the history of detection from ground to high altitude, introduces the circuits and principles of various meteorological observation instruments for temperature, humidity, air pressure, wind speed and direction, radiation, precipitation, as well as the signal acquisition system and data processing system [2] [3]. It also teaches observation methods for clouds, atmospheric electric fields, radio-sounding instruments, and small aircraft for detecting the upper atmosphere [4] [5]. Finally, it briefly discusses the physical models and statistical reanalysis methods for various meteorological observation data [6].

Innovative atmospheric sounding methods often lead to unexpected major discoveries. The field of atmospheric detection encompasses a vast and specific range of topics [7]. The course "Atmospheric sounding" mainly discusses the development of atmospheric sounding instruments, including the history of detection from the ground to the upper atmosphere [8]. The course also introduces the principles of various types of meteorological observation instruments, such as circuits, analog-to-digital conversion principles, signal acquisition systems, and data processing systems [9]. In addition, it covers observation methods for temperature, humidity, air pressure, wind speed and direction, radiation, precipitation, clouds, atmospheric electric fields, radio sounding, and small aircraft detection [10] [11]. Finally, it briefly describes the physical models and statistical reanalysis methods for various meteorological observation data [12].

The integration of new achievements in related fields such as electronic computing, microwave, signal data processing, and mathematics is critical to timely and effective innovation in atmospheric detection [13]. Upgrading and expanding exploration of atmospheric detection techniques relies on the application of novel meteorological sensors [14] [15]. One of the reasons for the rapid development of atmospheric science in the 20th century is the emphasis on the construction of observation systems and the application of new detection technologies. Several large-scale international research programs, such as the Global Energy and Water Cycle Experiment (GEWEX), the Climate Variability and Predictability Programme (CLIVAR), and the World Weather Research Programme (WWRP), prioritize the development of observation systems and actively promote the application of new atmospheric detection technologies [16] [17] [18]. Currently, a new generation of instruments and equipment, such as satellite remote sensing technology, unmanned aerial vehicle technology, phased array weather radar technology, laser application technology, and microwave radiometer technology, are advancing atmospheric detection capabilities [19]. These instruments and equipment are capable of producing larger volumes of observational data, and their information application levels continue to increase.

Standardized ground-based station network observation and recording for conventional meteorological elements and various atmospheric phenomena have been achieved. A new set of observational business systems, including dust storms, atmospheric composition, marine meteorology, agricultural meteorology, and aviation meteorology, have been established. Self-developed automatic meteorological stations and high-altitude detection systems have been put into business operation, while unmanned aerial vehicle-based detection equipment has entered the business system. Self-developed detection equipment has played an important role in meteorological observation business and the development of atmospheric science.

The course of Atmospheric Detection is a basic and practical professional course with strong application relevance, and its course content is continuously updated with the development of technology. The characteristics and innovative teaching reforms of this course are as follows: 1) emphasizing practicality: while introducing detection principles, practical abilities are also emphasized. Taking advantage of the comprehensive detection base jointly established by the China Meteorological Administration and Chengdu University of Information Technology, students are allowed to have contact with instrument entities, understand the operating principles of observation instruments, learn about the process of obtaining meteorological data, meteorological data formats, and their applications, and cultivate practical, composite, and applied talents. 2) Keeping up with the times: the continuous development of modern radio communication technology, remote sensing technology, electronic circuit technology, and computer technology has also promoted the development of detection technology. The physical environment scope of the Earth's atmosphere detected by humans continues to expand, and the amount of data obtained by detection also continues to increase. Therefore, the course content is continuously updated accordingly. 3) Emphasizing teaching innovation: Atmospheric Detection has a lot of content, but the number of class hours is relatively limited. Therefore, this course adopts a teaching method that combines teacher lectures, hands-on experiments, and student online virtual simulation platforms. The classroom mostly uses heuristic and discussion-based interactive teaching methods. Other virtual teaching cases built by other teams are introduced in the classroom, and students are encouraged to participate in meteorological observation and practice activities after class, which improves learning efficiency and helps students form intuitive and sensory understanding, and is beneficial to cultivate and shape students' innovative characteristics.

The course experiment design of this paper is to improve the detection of low-altitude meteorological elements. The advanced UAV system is equipped with detection equipment for sounding, which changes the traditional way of using balloons to carry radiosonde for sounding, and significantly improves the upper atmosphere detection method, which is the innovation of the experiment of text design.

2. Relevant Content Related to Atmospheric Detection Using Drones

Due to their convenience and flexibility, unmanned aerial vehicles (UAVs) have gained high popularity and innovation activity, leading to rapid development. The deep integration of UAV remote sensing and other related technologies has presented a plethora of expandable applications. We call this the "low-altitude UAV detection" application prospect, mainly manifested in the following aspects: 1) Real-time transmission of remote sensing data is crucial for military, emergency response, and disaster relief. Many national security monitoring and disaster relief operations rely on UAV remote sensing and real-time transmission to provide timely information for decision-making. In April 2019, during the resurgence of the forest fire in Muji, Liangshan, Sichuan, China, CCCC First Harbor Consultants Co. Ltd. used a UAV equipped with a three-axis stable dual-light electric suspension, taking off from an altitude of 3,000 meters, dynamically tracking and locking onto the fire point, storing and playing back in real-time, providing first-hand fire information for the emergency command center. 2) The combination of UAVs and simultaneous localization and mapping (SLAM) technology will enhance the navigation and obstacle avoidance capabilities of UAVs, with important application prospects in UAV intelligent data acquisition and autonomous flight. For example, indoor large scene positioning and map construction at the same time, outdoor large scene optical and lidar fusion three-dimensional reconstruction, can be convenient and fast surface buildings, indoor objects three-dimensional modeling. 3) Similar to the "observation and attack integration" in military applications, the integration of UAV remote sensing, identification, task planning, and execution technologies enables UAVs to complete tasks in a unified manner. For example, UAV remote sensing can be used to achieve remote sensing of field agricultural situations, generate pest prescription maps, plan reasonable flight routes, and execute precise pesticide spraying, integrating static remote sensing observations with real-time decision-making and execution.

However, in the field of meteorological detection based on large UAVs, China is still blank. To enrich meteorological prediction methods, the China Meteorological Administration has launched the first phase of the Oceanic Meteorological Comprehensive Guarantee Project, conducting unmanned aerial sounding experiments under the airborne observation subsystem. Using civil UAVs derived from the military high-altitude and high-speed UAV "YILONG" 10 as the core platform, an information exchange channel consisting of meteorological payloads, UAVs, ground systems, and meteorological networks is established for high-altitude meteorological data acquisition, filling the gap in China's large-scale UAV-based meteorological detection field. A successful flight with an unmanned aerial vehicle (UAV) surrounded Typhoon Sinlaku on 15 Sept., 2008 and the preliminary analysis of all the collected data during the observation period has been presented. It is the first time to adopt surrounding method to observe typhoon in mainland of China [20].

3. Course Design of Low-Altitude Meteorological Element Detection Experiment Based on Unmanned Aerial Vehicle (UAV)

The research on the course design of low-altitude meteorological element detection experiment based on unmanned aerial vehicle (UAV) will be carried out from three main aspects: the design of experimental course content, the design of experimental course steps, and the design of course practice modules.

3.1. Experimental Course Content Design

Teaching aids are the foundation of a curriculum. Currently, there are many rotary-wing unmanned aerial vehicle (UAV) platforms available, but few are suitable for use as teaching aids. Companies such as DJI and ZeroTech offer a variety of UAVs with stable performance. DJI's industrial UAV series, such as the DJI Matrice 300 RTK, has dimensions of approximately 810 × 670 × 430 mm (length × width × height) when unfolded (excluding propellers), and weighs 3.6 kg without the battery (**Figure 1**). It has a maximum ascent and descent speed of 5 m/s, a maximum flight time of 55 minutes, and a maximum flight altitude of 5 km. The DJI M300 RTK can be equipped with the "Lingxiu" series of

Figure 1. DJI M300 RTK equipped with meteorological detection instruments.

Figure 2. Preparations for a DJI M300 RTK test flight.

meteorological instruments developed by Shenzhen Kofly Technology Co., Ltd. to detect temperature, humidity, air pressure, wind speed, and wind direction in real time during flight. With the help of precise motion compensation algorithms, it can obtain accurate meteorological data without hovering. The Lingxiu V2 meteorological instrument supports three-axis wind speed measurement, and has motion compensation algorithms for UAV translation, attitude, and rotation, which can output wind speed and direction data in the northeast coordinate system after motion compensation, enabling accurate meteorological element detection during high-speed movement.

Course Content: This practical course is divided into three parts, starting from the basics and gradually progressing to more advanced topics:

1) Practice in operating a multi-rotor UAV;

2) Ground calibration of meteorological detection instruments;

3) UAV sounding experiments.

The course content is designed to ensure that students can operate UAVs independently, and based on their understanding of high-altitude meteorological detection, complete the final high-altitude meteorological detection using a UAV (Figure 2). This approach not only strengthens students' theoretical knowledge from textbooks, but also allows them to use practical skills. The course content aims to cultivate students' understanding of the high-altitude atmospheric detection system and their ability to construct a three-dimensional model of atmospheric pressure, temperature, and humidity changes. The last part will involve post-processing of high-altitude detection data, integrating all the knowledge into a comprehensive experimental course design.

3.2. Design of Curriculum Construction Ideas

The experimental design follows the CDIO engineering education model, with students at the center, and presents the complex process of atmospheric boundary layer detection using unmanned aerial vehicles carrying atmospheric sensors in a visual way. The aim is to cultivate students' understanding and awareness of low-level atmospheric detection in atmospheric science.

The purpose of experimental teaching is to cultivate students' practical skills. The mastery of practical skills can be divided into four stages: directional operation, imitation, integration, and proficiency. Students need to explore and gradually clarify the experimental content and steps in the actual operation process. In traditional teaching, students may find the theoretical and formulaic parts in textbooks very dry, and some scenarios are difficult to describe in words. However, hands-on experiments can transform theoretical teaching into rich practical teaching, which can improve students' interest in learning.

Firstly, students need to understand the breadth and depth of the project topic, as well as the system planning, functionality, and desired indicators, and plan and design the project based on extensive literature and team research and discussion, while reserving some time for learning knowledge. In order to better enhance the challenge of the unmanned aerial vehicle detection technology course, course construction will focus on the following aspects:

The integration of unmanned aerial vehicle hardware, data acquisition, and processing with the school, atmospheric science majors, and the "Atmospheric Detection" course characteristics to form a complete modular technology system. The modules can include unmanned aerial vehicle software and hardware system debugging and atmospheric detection modules, unmanned aerial vehicle practical flight and low-level meteorological element data acquisition modules, and unmanned aerial vehicle atmospheric detection data processing and application modules.

Combining unmanned aerial vehicles with the specific application of atmospheric science majors, integrating key and difficult knowledge points related to atmospheric boundary layer detection, and constructing a complete low-level atmospheric detection technology system. This can be reflected in the visualization of unmanned aerial vehicle detection data, the generation of three-dimensional atmospheric temperature and humidity profiles, and the low-level detection data application module.

Establishing an experimental verification platform that meets teaching needs, obtaining typical demonstration verification results, and constructing a more complete experimental teaching and practical teaching methods and rules.

3.3. Curriculum Practice Module Design

This system consists of meteorological load, mounting bracket, unmanned aerial vehicle platform, and ground control terminal. The meteorological load consists of a receiver, GPS antenna, sounding instrument, and post-processing software. The unmanned aerial vehicle platform consists of DJI's power system, wireless link, and bus control unit.

The ground control terminal serves as the main interface for human-machine interaction, sending control commands to the unmanned aerial vehicle platform via a wireless link. The bus control unit within the unmanned aerial vehicle platform sends the command to the mounting bracket and then to the meteorological load. The meteorological load receives the instruction from the unmanned aerial vehicle via a Type-C interface and periodically reports the status information back to the unmanned aerial vehicle. The unmanned aerial vehicle reports the information to the ground control terminal via a wireless link.

Inside the meteorological load, the receiver is used to collect data and transfer it to the sounding instrument. The sounding instrument measures the atmospheric temperature, humidity, and pressure during the flight of the unmanned aerial vehicle and transmits the measurement data back to the ground receiving station via wireless communication.

The course will use a three-level progressive practice mode, including: 1) Guiding basic experimental projects/skills training level; 2) Reflecting the depth and breadth of student participation/autonomous experimental level; 3) Challenging experimental projects/experimental level. The main practice modules involved in each level are as follows.

1) Guided basic experimental projects/skills

- Basic training in the operation of meteorological data processing software;
- Multi-rotor drone assembly, testing, and drone flight testing;
- Route planning and ground station software for drones;
- Data acquisition for unmanned aerial vehicle atmospheric sensors.

2) Demonstrating student participation in depth and breadth/autonomous experimentation

- Obtaining unmanned aerial vehicle boundary layer atmospheric detection data from the Sishan Observation Station and drawing temperature and humidity profiles (partially), and drawing wind rose diagrams (overall) (demonstrating the application level of unmanned aerial vehicle low-altitude atmospheric detection methods);
- Using the collected data to draw the temperature and humidity distribution map of the entire Sishan region for the low-altitude plane area (partially) (demonstrating the application of unmanned aerial vehicle high-altitude plane meteorological element collection).

In the experiment, the first step is to allow students to adjust the parameters of the unmanned aerial vehicle and the experimental instrument carried by the unmanned aerial vehicle, allowing students to become familiar with the steps and procedures for unmanned aerial vehicle takeoff, route planning, and high-altitude detection.

In the second step, after the unmanned aerial vehicle is assembled, the students will install the wind measurement and air temperature and humidity instrument payload on the unmanned aerial vehicle themselves. The teacher will open the portable computer and use the wireless transmission device of the DJI MK300 to input the unmanned aerial vehicle's flight height, flight route, flight time, and other information.

In the third step, the sensitive meteorological five-element equipment and ground receiving software are debugged, and the students record the ground pressure, temperature, relative humidity, wind speed, and wind direction information and compare it with the meteorological five elements collected by the payload for ground verification.

In the fourth step, if it is found that some meteorological elements deviate from the true value, it should be calibrated in time.

In the fifth step, the calibrated unmanned aerial vehicle and sensor are placed in an open field and prepared before takeoff.

In the sixth step, the unmanned aerial vehicle collects meteorological elements according to the designed route and height, and after completion, the collected data is analyzed and post-processed.

4. Conclusions

Traditional high-altitude atmospheric detection refers to using a sounding instrument carried by a balloon to sense the pressure, temperature, and humidity of the surrounding environment as the balloon ascends. The instrument transmits the data to the ground via wireless signals. After processing and analyzing the data, ground personnel can obtain the vertical distribution of atmospheric elements above the measurement station. High-altitude meteorology is a scientific discipline that experiments and studies the various physical phenomena and processes that occur in the free atmosphere. It investigates the distribution patterns of wind, pressure, density, temperature, humidity, etc., with altitude and latitude/seasonal changes, as well as macroscopic and microscopic cloud structures, precipitation processes, cold and warm fronts, squall lines, etc.

Due to its convenience, flexibility, high public participation, and innovation activity, unmanned aerial vehicles (UAVs) have developed rapidly and are widely used in atmospheric detection and other related technical fields. However, UAVs have limitations in terms of effective payload and flight time. Weather conditions such as rain, snow, clouds, and fog can restrict UAV activities and sensing processes. To enable the large-scale use of UAV detection technology, further improvements and enhancements to UAV capabilities are necessary. There are still some limitations in the design of this course. For example, when using drones for sounding, airspace needs to be submitted for application, and sounding cannot be carried out in no-fly areas. Due to the limitation of the battery capacity of drones, the flight height is about 1000 m, and it is impossible to detect high-altitude wind, but only the elements of atmospheric boundary layer can be detected. The upper atmosphere can only be explored by large fixed-wing drones.

The atmospheric detection course offered by atmospheric science majors should keep up with the new products and application scenarios of technological advancements, and strengthen the reform and innovation of experimental and practical courses in atmospheric detection. Through experimental course design, it is possible to achieve two objectives: 1) Keeping up with the forefront of high-altitude atmospheric detection technology, linking the key and difficult theories and technologies of related courses, exploring the combination points of cutting-edge technology and the major, and forming a challenging and demonstrative practical teaching course that closely links theory and practice, hardware and software. 2) Greatly enhancing students' hands-on and innovative abilities and cultivating cutting-edge and scarce talents that meet the urgent needs of meteorological industry employers.

Acknowledgements

This research is supported by the Undergraduate Education and Teaching Research and Reform Project of Chengdu University of Information and Technology: Ideological and political construction of Atmospheric Sounding Course.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Stevenson, M. (2012) Forecast Verification: A Practitioner's Guide in Atmospheric Science. John Wiley & Sons, New York.

[2] Hajj, G.A, Kursinski, E.R, Romans, L.J., *et al.* (2002) A Technical Description of Atmospheric Sounding by GPS Occultation. *Journal of Atmospheric and Solar-Terrestrial Physics*, **64**, 451-469. https://doi.org/10.1016/S1364-6826(01)00114-6

[3] Golden, J.H., Serafin, R., Lally, V., *et al.* (1986) Atmospheric Sounding Systems. In: Ray, P.S., Eds., *Mesoscale Meteorology and Forecasting*, American Meteorological Society, Boston, 1-5. https://doi.org/10.1007/978-1-935704-20-1_4

[4] Holland, G.J., McGeer, T. and Youngren, H. (1992) Autonomous Aerosondes for Economical Atmospheric Soundings Anywhere on the Globe. *Bulletin of the American Meteorological Society*, **73**, 1987-1998. https://doi.org/10.1175/1520-0477(1992)073%3C1987:AAFEAS%3E2.0.CO;2

[5] Stackpole, J.D. (1967) Numerical Analysis of Atmospheric Soundings. *Journal of Applied Meteorology and Climatology*, **6**, 464-467. https://doi.org/10.1175/1520-0450(1967)006%3C0464:NAOAS%3E2.0.CO;2

[6] Laloyaux, P., Balmaseda, M., Dee, D., *et al.* (2016) A Coupled Data Assimilation System for Climate Reanalysis. *Quarterly Journal of the Royal Meteorological Society*, **142**, 65-78. https://doi.org/10.1002/qj.2629

[7] Wilks, D.S. (2011) Statistical Methods in the Atmospheric Sciences. Academic Press, Cambridge.

[8] Collard, A.D. and Healy, S.B. (2003) The Combined Impact of Future Space-Based atmospheric Sounding Instruments on Numerical Weather-Prediction Analysis Fields: A simulation Study. *Quarterly Journal of the Royal Meteorological Society*, , **129**, 2741-2760. https://doi.org/10.1256/qj.02.124

[9] Meischner, P. (2005) Weather Radar: Principles and Advanced Applications. Springer Science & Business Media, Berlin.

[10] Li, L., Chen, T., Ti, S., *et al.* (2022) Fair-Weather Near-Surface Atmospheric Electric Field Measurements at the Zhongshan Chinese Station in Antarctica. *Applied*

Sciences, **12**, Article 9248. https://doi.org/10.3390/app12189248

[11] Nicoll, K.A., Harrison, R.G., Barta, V., *et al.* (2019) A Global Atmospheric Electricity Monitoring Network for Climate and Geophysical Research. *Journal of Atmospheric and Solar-Terrestrial Physics*, **184**, 18-29. https://doi.org/10.1016/j.jastp.2019.01.003

[12] Compo, G.P., Whitaker, J.S., Sardeshmukh, P.D., *et al.* (2011) The Twentieth Century Reanalysis Project. *Quarterly Journal of the Royal Meteorological Society*, **137**, 1-28. https://doi.org/10.1002/qj.776

[13] Mohsan, S.A.H., Khan, M.A., Noor, F., *et al.* (2022) Towards the Unmanned Aerial Vehicles (UAVs): A Comprehensive Review. *Drones*, **6**,147. https://doi.org/10.3390/drones6060147

[14] Emery, B. and Camps, A. (2017) Introduction to Satellite Remote Sensing: Atmosphere, Ocean, Land and Cryosphere Applications. Elsevier, Amsterdam. https://doi.org/10.1016/B978-0-12-809254-5.00011-7

[15] Emeis, S. (2010) Surface-Based Remote Sensing of the Atmospheric Boundary Layer. Springer Science & Business Media, Berlin. https://doi.org/10.1007/978-90-481-9340-0

[16] Chahine, M.T. (1992) GEWEX: The Global Energy and Water Cycle Experiment. *Eos, Transactions American Geophysical Union*, **73**, 9-14. https://doi.org/10.1029/91EO00007

[17] Karl, T.R., Nicholls, N., Ghazi, A. (1999) Clivar/GCOS/WMO Workshop on Indices and Indicators for Climate Extremes Workshop Summary. In: Karl, T.R., Nicholls, N., Ghazi, A., Eds., *Weather and Climate Extremes*, Springer, Dordrecht, 3-7. https://doi.org/10.1007/978-94-015-9265-9_2

[18] Ebert, E.E., Wilson, L.J., Brown, B.G., *et al.* (2004) Verification of Nowcasts from the WWRP Sydney 2000 Forecast Demonstration Project. Weather and Forecasting, **19**, 73-96. https://doi.org/10.1175/1520-0434(2004)019%3C0073:VONFTW%3E2.0.CO;2

[19] Ma, L., Li, M., Tong, L., *et al.* (2013) Using Unmanned Aerial Vehicle for Remote Sensing Application. 2013 21*st International Conference on Geoinformatics*, Kaifeng, 20-22 June 2013, 1-5. https://doi.org/10.1109/Geoinformatics.2013.6626078

[20] Li, Y., Ma, S. and Sun, Z. (2016) Analysis of Essential Meteorological Elements Surrounding Typhoon Sinlaku by Unmanned Aerial Vehicle. *Atmospheric and Climate Sciences*, **6**, 29-34. https://doi.org/10.4236/acs.2016.61003