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UAV Platform Based Atmospheric Environmental Emergency Monitoring System Design

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Abstract: Emergency monitoring is the basis for effectively preventing and dealing with the abrupt environmental accidents. Atmospheric environmental emergency monitoring system which is based on Unmanned Aerial Vehicle (UAV) platform, is characterized by high working efficiency, flexibility and wide-ranging monitoring. It provides a new technology platform and alternative tool, as well as opens up new branches. However, overall, the research of UAV platform-based environmental emergency monitoring in China is still in its infancy. A big gap exists with foreign countries in the development of miniaturization of high-precision airborne devices, monitoring data process, accurate modeling and integration of UAV and airborne devices. Additionally, research on systematical design on the UAV platform based environment emergency monitoring system is rare. Presented in this study was a design framework of the UAV platform based atmospheric environmental emergency monitoring system with regard to the components, functions and procedures. In addition, some fields needed to in-depth research in the future from the perspective of technology development, were put forward.

Key words: Unmanned aerial vehicle, atmosphere, emergency monitoring

INTRODUCTION

With rapid development of industrial economy, hazardous chemicals have experienced a rapid growth in either category or quantity. Meanwhile, abrupt environmental accident due to their unsound safety production, management, storage, transportation or usage also presents an increasing trend (Chen *et al*., 2005). According to the incomplete statistics from Center of Environmental Emergency and Accident Investigation of Ministry of Environmental Protection, the number of abrupt atmospheric pollution accidents had been up to 263 during the period of 2004-2009. This number accounts for 37.1% of the total 709 major environmental accidents in China (Taiwan Province not included) (Shao *et al*., 2009). Moreover, it is worth to note that abrupt atmospheric pollution accident is a special kind of atmospheric pollution accident, characterized by unpredictable, irreversible, harmful and emergent and once happened, serious impact will be exerted on the ecological environment, people's health and social stability (Chen *et al*., 2011). Therefore improvements on emergency response of environmental abrupt accident are very essential, in the process of which environmental emergency monitoring plays an especial important role. It can obtain on-site dynamic information about category, pollutants concentration distribution, influence scope and developmental trend of the accident. The information can help government departments win precious time for rapid and accurate emergency decision making, so, as to effectively control pollution scope, shorten the duration time and finally minimize the loss of the accident. Consequently, research on emergency environmental monitoring is urgently needed.

UAV (unmanned aerial vehicle) based remote sensing technology is an application technology which uses advanced UAV, remote sensors, telemetry and telecontrol system, communication system and GPS differential

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positioning system. It is characterized by automation, intelligence, specialization and rapid in data (i.e., the land, resources and environment spatial information) acquisition, processing, model building and analysis (Hu, 2009). Its application in atmospheric environment emergency monitoring system has been one of the important future developmental directions. The atmospheric environment emergency monitoring system based UAV platform has advantages of high working efficiency, flexibility, wide-ranging monitoring and less terrain interference. It could compensate the shortage of traditional system which mainly consists of environmental monitoring vehicles and portable device. The relevant research of it has been gradually carried out at home and abroad recently (IAP and CAS, 2008). For example, some attempts on monitoring polluted air mass by multi-UAV collaborative system has been conducted abroad in terms of searching method of unknown environment, environment map modeling, task allocation and path planning (White *et al*., 2008; Kovacina *et al*., 2002). In China, Chinese Academy of Science Institute of Atmospheric Physics designed two models of micro-UAVsand did sounding experiment with devices of improved ozone sensors and particles detector (number or mass concentration) as well as temperature and humidity sensors. Results showed that the flight monitoring data gotten was reasonable and credible. Also, Chinese Academy of Sciences Anhui Institute of Optics Fine Mechanics used the platform equipped with air pollution differential absorption spectroscopy detection systems and successfully obtained the two-dimensional space-time distribution of NO_2 etc., however, overall, the research of UAV platform-based environmental emergency monitoring in China is still in its infancy. A big gap remains with foreign countries in the development of miniaturization of high-precision airborne devices, monitoring data process, accurate modeling and integration of UAV and airborne devices. Additionally, research on systematical design on the UAV platform based environment emergency monitoring system is rare.

The aim of this paper is to propose a system framework of UAV remote sensing platform based atmospheric environment emergency monitoring system. It systematically analyzes the composition, structure and operation of UAV remote sensing platform from the perspective of UAV platform, airborne devices and supporting software design. Some key issues in system construction were also discussed for reference.

MATERIALS AND METHODS

System framework and components: A complete set of overall framework of the UAV platform based atmospheric environmental emergency monitoring system is shown in Fig. 1.

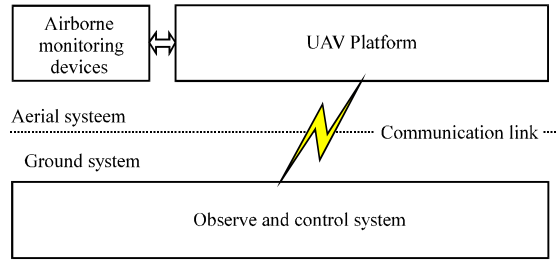

Fig. 1: Components of the UAV platform based atmospheric environmental emergency monitoring system

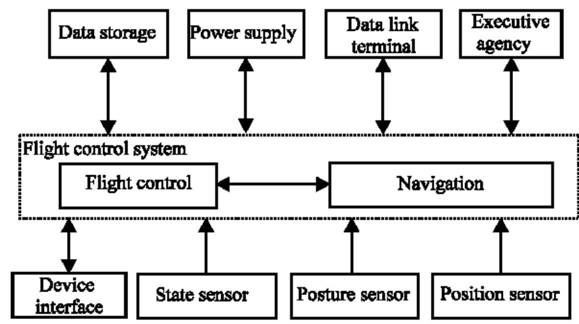

Fig. 2: Composition of the flight control and navigation system

Unmanned aerial vehicle (UAV) platform: In the entire monitoring system, UAV is a platform that can fly in accordance with the specified track and can carry the airborne monitoring device. The core of a UAV platform is the flight control and navigation system which consist of flight control computer, navigation and positioning computer, airborne sensors groups, servomechanism and airborne power supply system. The composition of the flight control and navigation system is shown in Fig. 2.

Airborne monitoring devices: The airborne monitoring devices of the UAV platform based atmospheric environmental emergency monitoring system include: gas monitoring devicesand video or image monitoring devices. According to the sampling method, they can be divided into two kinds: Two-dimensional planar aerial photography based spectrum device (such as thermal infrared imager, the light infrared aerial sweep instrument, infrared scanners, microwave radiometer, etc.,) and the pump suction punctate sampling based airborne gas monitoring device (such as particle detectors, differential optical absorption spectroscopy detection systems, the electrochemical gas monitoring devices, etc.,). Airborne

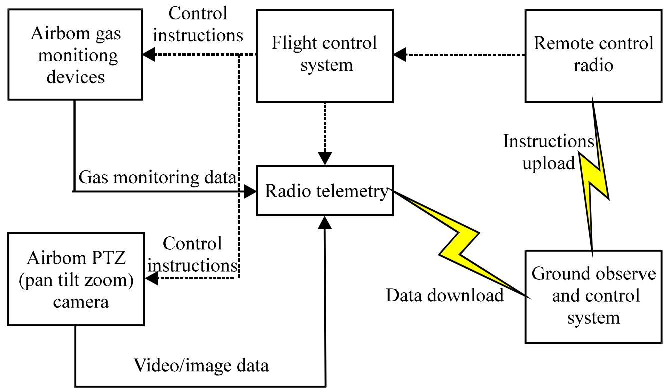

Fig. 3: Communication link (airborne monitoring devices and flight control system shared radio telemetry)

adaptive improvement has been made on mature miniaturized multi-gas detection devices by the research and development (R and D) team of Institute of Resources and Environment Science, Mapuni (IRESM). These devices can be applied for rapid monitoring of high concentrations of toxic and hazardous gases in abrupt atmospheric accidents. The main performance indexes are as follows: Dimensions: 300×260×490 mm; weighing: Less than 15 kg, operating temperature: -20 °C °C~50 °C; pump suction sampling; H_2S, CO, NO_2, SO_2, O_2 detectable and scalable; measurement limit is up to 1 ppm, accuracy within±5 %.

Communication system: The reserved data interfaces of radio telemetry on UAV platform can be directly used by airborne gas monitoring devices for data transmission. On the Z-3 domestic unmanned helicopter platform (made by the 60th Institute of the Headquarters of the General Staff of Chinese People's Liberation Army, Nanjing, China), the devices for visual surveillance and gas monitoring were integrated for atmospheric environmental emergency monitoring system building by the R and D team of IRESM. Its communication link is shown in Fig. 3. This means of communication has a high intensification and does not have to increase the number of digital transmission radio or figure transmission radio thereby reducing the payload capacity. However, the secondary development on the flight control system of UAV is needed to achieve data accessing between monitoring devices.

In addition, data transmission can also be accomplished by building airborne monitoring devices data link through adding digital transmission radio or figure transmission radio to the UAV platform. In this way, the monitoring data transmission is independent on the flight control system; and there is no need to develop data interfaces based on the flight control system, however, it will increase the weight of mission payloads.

Ground flight observation and control system: Ground flight observation and control system includes ground control system of the UAV platformand environmental emergency monitoring system for the airborne devices monitoring data analysis. Specifically, a UAV Ground flight observation and control system consists of the following parts in general: Observe and control platform; hock-proof LCD monitor, image recording device; industrial computer, observe and control receiving device; image pick-up device; remote manipulator (inside), remote manipulator (outside); the airborne device controller, generator; UPS and power supply system; antenna and control system; telemetry software package, antenna lift rod, etc.

The environmental monitoring system is customized according to the data protocol of airborne monitoring devices, can be seamless integrated with flight control system when the data interfaces of flight control system are open.

During environmental emergency platform building process, ground flight observation and control system can be integrated with the emergency command vehicle.

Operation procedure: The entire implementation process of the UAV remote sensing platform based atmospheric environmental emergency monitoring system mainly can be divided into the following 4 stages.

Take-off preparation stage: First, determine the exact survey area in the topographic map, such as earth latitude, longitude and elevation data, according to the needs of the monitoring. Then obtain local meteorological data and make sure it is suitable for the UAV flight. Once

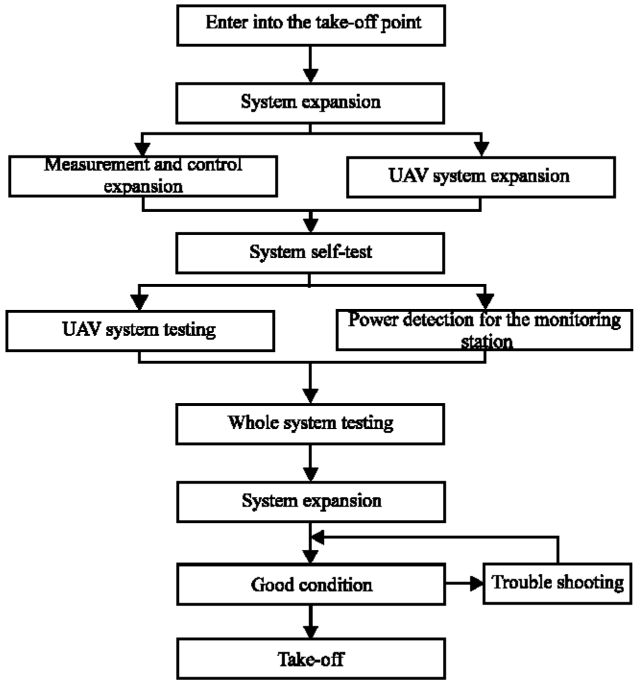

Fig. 4: UAV (unmanned aerial vehicle) take-off preparation phase

the UAV reaches the scene or the nearby incident place, it comes to the take-off preparation phase.

As shown in Fig. 4, the UAV take-off process mainly includes entering into the take-off point, system expansion and the system self-test, whole system testing and take-off stage.

Working stage: First of all, focus on monitoring regional route planning, intend the flight altitude, waypoint and track, build the signal transmission frame at the ground control station. Then the UAV would take off when entered the flight instruction, using the remote control to guide it into the scheduled flights, large-scale searching for gas leakage and pollution sources and would fly over the target once find it.

In this process, the remote control system will follow the default routes and monitoring methods (such as gas sampling frequency, video surveillance etc.,) to control the monitoring devices. The remote sensing data, control parameters and other information would transmit among the sensors, UAV platform and ground control station during the flight and the information would real-time display at the ground station. The UAV can automate flight, can also change the flight at any time according to the ground control personnel needed to track task or focus to the supplement regional monitoring. With the help of airborne gas monitoring devices and video surveillance devices, real time transmitting the video, gas concentrations and other information to the ground station, the ground staffs can process and analyze the information.

Recovery phase: In this stage, power off the remote sensing devices after the UAV completed the scheduled missions. The UAV recovery phase includes recovery course determination, recovery of flight control, landing, engine-off and recovery five steps.

Data processing and analysis phase: The last stage of the system implementation is to use the data-processing software for real-time processing and analysis of the gas monitoring data and video first. Then the ground station operator can timely transmit the data to the emergency command center through the emergency communication system which provided important material for emergency response decision-making.

RESULTS

Considering the needs of the UAV platform based abrupt atmospheric environmental emergency monitoring, ground flight observation and control system mainly includes two parts from the perspective of software function: UAV control system and emergency monitoring system.

UAV control system: Functions of UAV control system mainly include:

- **Flight status display:** Two parts included: Flight path display and flight parameter display. Through communication network, system gets the GPS latitude and longitude information from the ground control station in real-time by radio link. According to the positional information gotten, the flight position can be displayed in the view intuitively by small plane icon, in which the small plane icon could rotate according the course. The flight parameter functions include aircraft attitude indicator, flight control directive instructs, flight status indication and fault alarm indication
- **Route planning:** When executing environmental monitoring mission in an area, the UAV would implement a reference route in accordance with order and monitoring emphasis previously made which may need to be adjusted or revised in a timely manner according to the monitoring requirement. After the mission planning, ground control station would upload the data to the UAV autopilot via a radio link
- **Route playback:** After obtaining and saving data during the process of UAV flight, scene can be reproduced through the function of "flight routes playback" and thereby facilitate the analysis of the UAV flight conditions and implementation of the mission

Emergency monitoring system:

- **Toxic gas monitoring system:** The main achievement of toxic and hazardous gas monitoring subsystem is dynamic display, process and analysis of gas monitoring data, such as real-time data view, high concentration alarm, statistical analysis, report output *et al.* For multi-point monitoring data, the gas concentration distribution is also able to be displayed basing on three-dimensional GIS platform and the sampling point coordinates
- **Video monitoring subsystem:** Functions of video monitoring subsystem include: (1) Remote control of video surveillance devices, shooting angles and focal length, etc., (2) Real-time display of video monitoring information in ground stations, (3) Calling a professional image stitching software to interrelate all the overlapping images in the video stream, so as to generate a seamless and clear image in real time through preprocessing, registering and splicing and to expand range of vision

Specific achieving ways: Firstly, obtain real-time video image through a video capture device and de-frame. Secondly, preprocess every frame video image in the way of histogram equalization and edge extraction. Thirdly, make use of the correlation among images to register and then stitch them to form a panoramic image of the big visual field (Kang and Pang, 2008):

- **The emergency assistance decision making subsystem:** In this part, according to the needs of abrupt atmospheric environmental emergency accident, functions like hazardous chemical information management, simulation analysis of atmospheric pollution's diffusion, emergency response preparedness management, emergency monitoring handbooks *et al.*, are provided which are based on atmospheric monitoring information

DISCUSSION

It is a new project for taking UAV platform for emergency monitoring of the abrupt atmospheric pollution accidents, there are many issues to research and resolve and here are some of the important issues briefly discussed by author as follow:

Selection of UAV platform: Common UAV includes two types: Rotor UAV and Fixed-wing UAV which have their own advantages and disadvantages in the atmospheric environmental monitoring. In the abrupt environmental accidents, Rotor UAV could be made to hover in the air of target area when emergency monitoring, especially suitable for small-scale video surveillance or multi-angle aerial photography at emergency scene. However, in the process of high-precision monitoring (for example: Routine air quality monitoring accuracy up to 1 ppb), the large airflow disturbance will impact the measuring accuracy greatly. Generally, Rotor UAV with advantage of good flexibility and maneuverability is chose in the condition of a wide range of atmospheric pollution investigation or qualitative monitoring, because high atmospheric environmental monitoring accuracy is not required in those cases. In comparison, small multi-rotor UAV, as a lightweight UAV system, has small airflow disturbance. For example, SCANCOPTER X6 UAV systems equipped with a small electronic nose (E-Nose) as atmospheric environmental monitoring device has been successfully used for the detection of industrial malodorous emissions in the foreign countries. However, the mission payload capacity of small multi-rotor UAV is limited and the endurance is shorter, rarely taking as emergency monitoring platform for the abrupt atmospheric pollution accident.

For fixed-wing UAV, only enough speed satisfied, the required lift has the ability to maintain a balance of itself. As a result, it is unable to meet the monitoring requirements of hovering. However, it has an advantage of small airflow disturbance. So, in the condition of requiring high precision of atmospheric environmental monitoring, it is often an alternative. However, for avoiding the interference emissions by UAV itself for the atmospheric environmental monitoring, the gas intake port should be usually reasonable reset, such as taking use of fixed-wing UAV with rear mounted engine and front gas sampler.

In addition, it is worth noting that comprehensive consideration should be made in the selection of UAV platform. In one hand, the UAV load capacity should meet the task requirements of flight. On the other hand, from the view of software development, it is necessary to consider the problem of data interface with the flight control system, in order to meet the need of the atmospheric environmental monitoring data and video data or image data analysis.

Selection of airborne monitoring devices: The selection and research of airborne atmospheric environmental monitoring devices is the key to a successful system-building. However, at present, the UAV remote sensing technology of atmospheric environmental monitoring is still in the primary stage in China. As a result, domestic relevant research on airborne special monitoring device especially in types of miniaturization and lighter remain an emerging field. While in foreign countries, study on the airborne devices using technology of remote sensing flourier transform infrared spectroscopy (RS-FTIR) has entered a mature application stage. For instance, the titan gas analyzer developed by MIDAC (U.S.) achieved the integration of airborne operations and atmospheric environmental monitoring data processing. These high-cost devices with large volume and quality, will have high requirements for the stability of the UAV platform and payload and has not been widely used in the country currently. The domestic research and development for the devices of aviation measuring aerosol that suitable for low-altitude, low-temperature, low-pressure environment conditions has been launched. There are some advantages of small, lightweight, quick measurement and low devices investment for the atmospheric environmental monitoring devices which was based on gas sensor development, taking airborne transformation for this type of devices and performance testing for the UAV telemetry. In case of less precision for emergency monitoring, it is also an available option for a low cost at this stage. Especially the atmospheric environmental monitoring devices that based on the sensor array technology with gas recognition function, there would be better prospects for the application of quantitative discrimination and measurement during the process of emergency monitoring.

Selection of communication link: Communication link is chosen in accordance with the capacity of UAV and the mission of flight. The early data link adopted organization system characterized by remote control, telemetry, video transmission, tracking and positioning channels separately. After the 1980s, the comprehensive unified carrier system is widely used in order to simplify the devices and save spectrum. In this unified carrier system, the signal path could be integrated in different degrees to composite different forms of UAV data link according to the needs and possibilities. "Three in one" and "Four in one" are the frequently used signal path system of UAV data link. The "Three in one" system is a carrier system with tracking and positioning, remote control and telemetry channel unified. In the system, the telemetry channel is used to track angle measurement; the telemetry and remote control channel is used to measure distance; the separate downlink channels are used to transfer video information. The "Four in one" system is a carrier system with tracking and positioning channel, remote control channel, telemetry and information transmission channel unified, in which the telemetry channel is used to track angle measurement, the telemetry and remote control channel is used to measure distance and one channel is shared to transfer video information and telemetry. There are two modes for sharing one signal path to transfer video information and telemetry. One mode is that the analog video signal and the subcarrier of telemetry data are transmitted separately while the other one is that they are combined transmitted. The problem of high precision automatic tracking of antenna which receives the broadband modulation signal should be solved if adopt the "Four in one" signal path system. Since, the comprehensive degree of signal path is so high, the "Four in one" signal path system is widely adopted in the data link of UAV. However, the "Three in one" signal path system also has certain flexibility because of the separation of broadband and narrowband signal channels (Zhou, 2008).

At present, the transmission distance and transmission mate of wireless transceiver is less than microwave devices. If use a large UAV as a carrier, the microwave link is the better choice under the requirements of more than 50 km operating radius and higher-resolution ground target detection. The global operational capabilities could be obtained even using a satellite communications link with the availability of economy and the UAV platforms.

Software development: Developing software of UAV platforms based atmospheric environment emergency monitoring system to provide decision support for emergency response is a system engineering. There are also many technical bottlenecks especially in data processing and decision analysis.

High-speed and effective video image stitching technology is the key to obtain accident information rapidly. As the image quality usually affected by the UAV flight condition, it is difficult to meet the traditional requirements of aerial triangulation entirely. Therefore, traditional aerial photography could not be totally used in the UAV images processing.

In the absence of other control point data, how to match, splice and correct UAV images rapidly only using secondary data of UAV images and the UAV system themselves has become the hot spot in research field of UAV based remote sensing. Related studies show that SIFT algorithm has better prospects in this process (Gong *et al*., 2010). However, there are still none mature system for image processing currently and the interrelated processing software is also rare. Great efforts are still needed for relevant research and mature product of software system.

For gas monitoring data, how to quickly and efficiently get distribution and development trends of pollutants based on monitoring information, provide decision support for environmental emergency response, is a core issues of software development. On the one hand, it needs improving on the accuracy and efficiency of airborne gas monitoring devices. On the other hand, it relies on efficient model technology development and application. It still remain to be studied that how to achieve real-time data assimilation between air monitoring data and atmospheric pollution diffusion model based on UAV platforms, to achieve advanced back-stepping calculation of source intensity using real-time density of measurement, improve the operation efficiency of the model significantly and predict the trends of pollution dispersion.

In addition, how to execute fusion analysis of the UAV platform based gas monitoring data and ground monitoring data, to achieve "air-ground integration" collaborative monitoring and analysis is also one of the directions of future research.

CONCLUSION

Compared with traditional system with environmental emergency monitoring vehicle and portable gas detection devices as the mainstay, UAV platform based atmospheric environmental emergency monitoring system has advantages of real-time, flexibility, high-resolution, low cost and without risk when collecting information in dangerous environments. It provides a new option for emergency monitoring to deal with the abrupt atmospheric pollution accident and opens up new branches. As an important complement, it will be integrated with traditional systems. However, in present, the construction of relevant system is still in the research stage. Although, some of the achievements have had the ability of commissioning, test is still needed with regard to cost, work capacity and benefit.

In the future, great efforts should be made to further promote the research and application of UAV platform based atmospheric environmental emergency monitoring system in the following aspect:

- **Instrument development:** Promote the research of atmospheric aerial surveying and other relevant technology and attain independent intellectual property rights of the key hardware device and software system
- **Research on integration of UAV platform based atmospheric environmental emergency monitoring system and environmental emergency commanding platform:** In one hand, considering the complementarity of aerial surveying and ground monitoring, multi-layer environmental emergency monitoring network should be construct. In another hand, the study on the integration of monitoring data collection, data processing and emergency command through standardized database system should be strengthened to enhance the comprehensive ability of environmental emergency
- **Software for data analysis and processing:** Great emphasis should be put on technology research of unmanned aerial vehicles images and rapid splicing and rectifying which only uses auxiliary data recorded by unmanned aerial vehicle (UAV) system itself, without control point data. Moreover, further study should focus on data assimilation between monitoring data and atmospheric dispersion model.

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REFERENCES

Chen, Y., X.B. Zhang and M.X. Wang, 2005. Emergency environmental monitoring technology for sudden air pollution accident. City and Industry and Safety, China, pp: 28-31 (In Chinese).

Chen, W., S. Chen, E. Du and Y. Wang, 2011. Design and development of emergency monitoring system to sudden air pollution accidents. J. Geo-Inform. Sci., 13: 65-72.

Gong, A.D., X.Y. He, T.J. Lei and J. Li, 2010. Fast image processing method of UAV without control data. Geo-Inform. Sci., 12: 254-260.

Hu, K., 2009. UAV platform based earthquake monitoring system. Sci. Technol. Assoc. Forum, 1: 100-101.

IAP and CAS, 2008. The flying detection load experiment using atmospheric environment monitoring s ystem based on micro-UAV in Institute of atmospheric physics was a success. Sci. Technol. West China, 7: 35-36 (in Chinese).

Kang, Y.X. and C. Pang, 2008. Application of real-time video mosaic imaging in system. Radio Eng., 38: 26-28 (in Chinese).

Kovacina, M.A., D. Palmer, Y. Guang and R. Vaidyanathan, 2002. Multi-agent control algorithms for chemical cloud detection and mapping using unmanned air vehicles. Intell. Robots Syst., 3: 2782-2788.

Shao, C.F., M.T. Ju and Y.F. Zhang, 2009. Environmental risk assessment and management of sudden air pollution accident. Environ. Sci. Technol., 32: 200-205 (In Chinese).

White, B.A., A. Tsourdos, I. Ashokaraj, S. Subchan and R. Zbikowski, 2008. Contaminant cloud boundary monitoring using network of UAV sensors. IEEE Sensors J., 8: 1681-1692.

Zhou, X.S., 2008. Overview of UAV TT and C and information transmission technology development. Radio Eng. China, 30: 30-33 (In Chinese).