Chapter 2

A UAV REMOTE SENSING SYSTEM: DESIGN AND TESTS

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2.1 Introduction

Airborne remote sensing refers to reconnaissance techniques using aircraft, balloon, or other platforms. Comparing to satellite remote sensing, it has four main advantages: relative low cost, flexibility in the frequency and time of data acquisition, and the ability to record spatial details finer than current satellite technology can (Mei *et al.* 2001).

With the development of sensors and communication techniques, high resolution airborne remote sensing has been successfully applied to large-scale topographic mapping and surveying for detailed ground information. Although conventional airborne remote sensing has some drawbacks, such as altitude, endurance, attitude control, all-weather operations, and monitoring of the dynamics, it is still an important technique of studying and exploring the Earth's resources and environment.

Airborne remote sensing can be categorized to manned aerial vehicle remote sensing and unmanned aerial vehicle (UAV) remote sensing according to the platform. The name UAV covers all vehicles which are flying in the air with no person onboard with the capability of controlling the aircraft (Eisenbeiss and Zhand 2004). Thanks to GPS and communication technology, UAVs can be remotely controlled or flown autonomously based on pre-programmed flight plans or more complex dynamic automation systems.

Over the past years, with the rapid development of micro-electronics, communications, and materials and propulsion systems, research on UAV has made an obvious progress. The number of UAV systems is growing fast, and most of them are for military use or part of a development project (Blyenburgh 2008). In this international activity, 49 countries around the world are involved (Europe: 23; Asia: 14; South-America: 4; North-America: 3; Australia: 2; Africa: 2) (Everaerts 2008). Some typical UAV are the Darkstar (Lockheed Martin and Boeing, USA), Predator (General's Atomic Energy, USA), Heron (Aircraft Industries, Israel), and Alenia Mirach (Italy). Several UAV models are shown in Fig. 2.1 (www.livingroom.org.au/uavblog). Take the most well-known UAV "Global Hawk"

D. Li et al. (eds.), *Geospatial Technology for Earth Observation*,
DOI 10.1007/978-1-4419-0050-0_2,

as an example. It flies at an altitude of more than 10,000 m with a fuselage of 13.5m long and 4.62m high, a wingspan of 35.4m, maximum take-off weight of 11,622kg, maximum payload of 885kg, cruise speed of 635km/h, practical ceiling of 20,500m. So far, it is the largest UAV that can implement a high-altitude, long-distance and long-time continuous reconnaissance mission http://www.livingroom.org.au/uavblog/archives/1_global_hawk.jpg. It uses a variety of cameras including electro optical and infrared and has capabilities of transmitting pictures in real time to bases.

a b c

Fig. 2.1 Examples of unmanned aerial vehicles: (a) Predator; (b) Cypher; (c) Global Hawk. The images are from http://www.livingroom.org.au/uavblog/archives/Predator-UAV_nh_100201.jpg

UAV remote sensing system is based on UAV which has both the common characteristics of aerial remote sensing and its own unique features. Compared with manned aerial vehicles, remote sensing systems with the platform of UAV can work all-day and all-weather and perform flight tasks in high-risk areas. Moreover, UAVs are able to operate rather close to the object and acquire images with few centimeter resolution (Eisenbeiss and Zhand 2006), providing sufficient detail.

Due to the cost of the mission, the need for rapid response or the fact that observations need to be carried out in an environment that may be harmful or dangerous to an aircrew, scientific interest in this type of platforms is growing, and a number of experiences have already been reported (Berni *et al.* 2009). Many remote sensing applications have benefited from the use of UAVs. A remarkable example is the adoption of remote sensing using UAVs in archaeology (Çabuk *et al.* 2007, Eisenbeiss and Zhand 2006). UAVs have also been used successfully in vegetation monitoring (Herwitz *et al.* 2004, Rango *et al.* 2006, Berni *et al.* 2009), and in Japan these systems are considered to be an integral part of farm equipment. With the ability to get close to the object, they were also used for road condition assessment (Zhang 2008). Rapid response imaging using UAVs has received a lot of attention as well (Everaerts 2008). This has been demonstrated in road accident simulations (Haarbrink and Koers 2006) and in many cases of forest fire monitoring (Réstas 2006, Martínez-de Dios *et al.* 2006). UAVs have also been proposed as platforms to monitor volcanoes (Puri *et al.* 2007, Doherty 2004). Some UAV systems have also used Lidar and SAR (Wang *et al.* 2009, Edrich 2006).

Besides the UAV with a fixed wing, there are many other kinds of UAVs, some of which even were used in remote sensing before the manned aircraft. In some sense, the kite is the simplest and most primitive model of the UAV. M. Arthur Batut took the first aerial photograph using a kite. It was taken over Labruguiere, France in the late 1880s.

A tethered balloon (Çabuk *et al.* 2007, Vierling *et al.* 2006) or blimp is also a simple UAV. Fig. 2.2 shows a modern blimp (en.wikipedia.org/wiki/Blimp). It is easily controlled (especially its altitude), but of course quite unstable if the wind speeds increase. The balloon can be adapted to the size and mass of the instruments that need to be carried. Tethered balloons have been widely used for remote sensing purposes for over a century. In 1858, Gaspard Felix Tournachon (later known as "Nadar") captured the first recorded aerial photograph from a balloon tethered in Paris, in which the houses can be seen clearly (Robert 1975). Recently, true color and infrared aerial photographs taken from balloons or kites have been used in photography-based studies of periglacial features, vegetation growth, and soil properties (e.g. Boike and Yoshikawa 2003, Buerkert *et al.* 1996, Friedli *et al.* 1998, Gerard *et al.* 1997, Chen and Lee 2006).

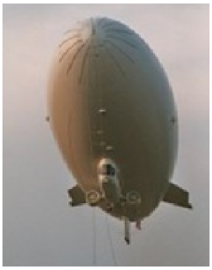


Fig. 2.2 A modern blimp

Fig. 2.3 An unmanned powered paraglider (Thamm and Judex 2006)

Fig. 2.4 Yamaha R-MAX

Unmanned powered paragliders (Fig. 2.3) are interesting because they need very little ground support, use proven technology, carry substantial loads, and are low-cost compared to other low-altitude systems(Everaerts 2008). They have been flown successfully in remote areas that cannot be addressed economically with conventional survey equipment (Thamm and Judex 2006).

Another kind of UAV is the unmanned helicopters which come in many types and sizes. Some companies already use helicopters with/without GPS navigation for the production of aerial imagery of single buildings and cities or for documentation of industrial constructions. Zischinsky *et al*. (2000) used images taken from a modelhelicopter partly for the generation of a 3D-model of a historical mill. Fig.2.4 (www.livingroom.org.au/uavblog) shows the model of RMAX which came out in the year 1997 and was equipped with an azimuth and a differential GPS sensor system 3 years later. The RMAX UAV system from Yamaha was successfully used as a ground truth measurement system (Hongoh 2001). In Japan, hundreds are used in agriculture as platforms to plough, sow, spray, etc (Everaerts 2008).

UAV is playing a more and more important role in land resource surveying, city planning, environmental protection, pollution monitoring, disaster monitoring, and other applications. This chapter introduces the design and tests of an airborne remote sensing system based on UAV. In the following sections, a real sample of UAV remote sensing system will be introduced.

2.2 UAV Remote Sensing System

The architecture of the proposed UAV remote sensing system is shown in Fig. 2.5. One or more unmanned airplanes may serve as the airborne remote sensing platform. Even though the UAV can fly automatically under the control of the preset program, it is always controlled and monitored from the Ground Control Station, so it needs reliable communication links to and from the aircraft. The Ground Control Station provides a working space for a pilot, navigator, instrument operator and usually a mission commander. The sensors onboard are controlled by the airborne control system to capture images of the working area. After basic and real-time processing on board, the data can be downloaded to the Ground Control Station for on-site processing or forwarded to a processing center. The data processing center or ground receiving station will then further process, archive, manage and distribute the data for expert users. Advanced processing may involve information extraction and application of RS images. This way the business operation of the UAV remote sensing system is formed and a complete set of protocols and standards can be realized.

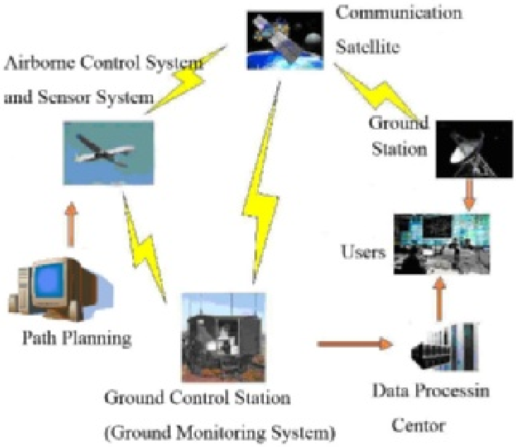


Fig. 2.5 General view of the architecture of UAV remote sensing system

In general, the four core components of a UAV remote sensing system include remote sensing airborne control system, remote sensing ground monitoring system, multimode airborne digital camera system, and automatic path-planning system. They are respectively introduced in the following subsections.

2.2.1 Remote Sensing Airborne Control System

The unmanned airplane implements automatic judgment and performance. Once a malfunction occurs in any component or module of the UAV remote sensing airborne control system, the quality of the results will be affected. Therefore, the design and development of a stable and reliable remote sensing airborne control system is the primary task for the implementation of unmanned airplanes for remote sensing.

The remote sensing airborne control system carries out positioning, camera auto-triggering, and data storage and transmission between the camera and the unmanned airplane platform, etc. It can implement fast update and reliable connection between airplane and remote sensing sensors. It can also load different kinds of remote sensing sensors which meet the requirements of interfaces.

2.2.1.1 Composition

According to the task demands, the control system is constituted of three modules: the photographing control module, data processing and transmission module, and power supply management module, which are depicted by Fig. 2.6.

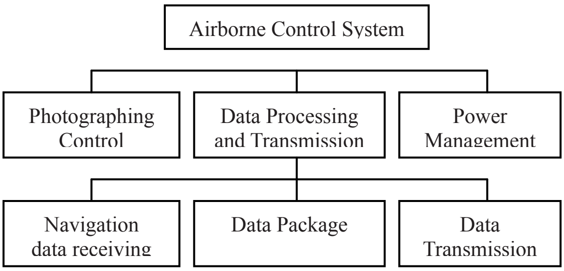


Fig. 2.6 Composition of remote sensing airborne control system

1) Photographing Control Module

This module is the core of the whole airborne control system. Since the survey tasks lay much emphasis on data accuracy, different control strategies should be adopted according to topographies and weathers. In this module, two schemes are available. The first scheme is to photograph by triggering the camera shutter in fixed time interval. The second scheme is to photograph at fixed positions. When the airplane enters the target regions according to the position information from the unmanned airplane, it will automatically take pictures. Because the airflow disturbance has much influence on the flight route of the unmanned airplane, some places will be redundantly photographed and there exist some gaps or incompletely photographed regions if the first scheme is adopted in bad weather. In this condition, the airplane must accurately photograph at selected positions. The flowchart of photographing control procedure is illustrated in Fig. 2.7.

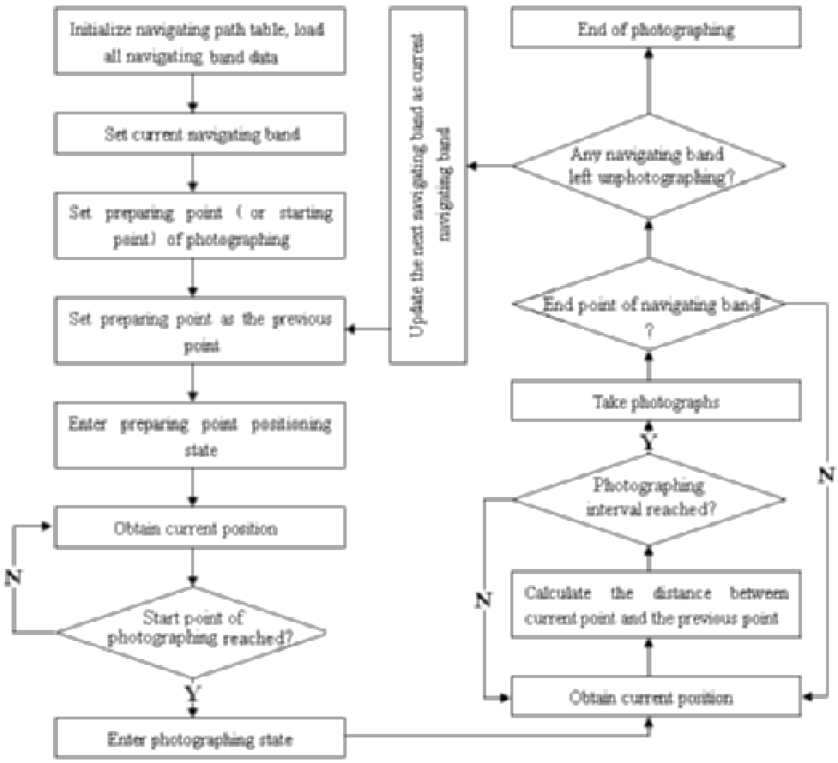


Fig. 2.7 Flowchart of UAV photographing control

2) Data Processing and Transmission Module

After the scene is photographed, the raw images are stored in the airborne storage and sub-sampled to be transmitted to the control system. The data processing and transmitting module packages the information such as position, attitude, and time and image data, and then sends them to the ground.

3) Power Supply Management Module

The unmanned airplane contains a 27V DC power supply, while in general the power supply of industrial compute is 5V or 12V. Thus voltage must be converted before being used. The power supply management module transforms voltage, provides stable power output, and controls the power supply of the industrial computer system.

2.2.1.2 Software Design

This subsystem's main control software is a multi-thread program including three main threads: the position and attitude data acquisition thread, image data acquisition thread, and photographing control thread.

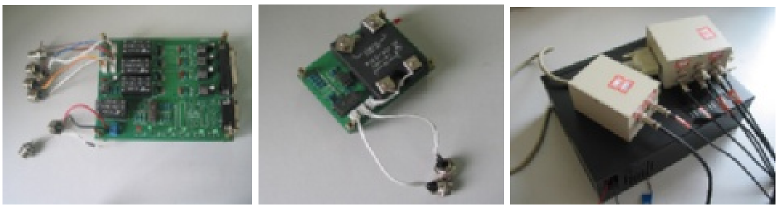
The position and attitude data acquisition thread receives data of the plane by the low speed RS422 interface, and these data will be transmitted to the photographing control program for further processing.

The image data acquisition thread receives the snapshots transmitted from the camera system. The communication mode adopts C/S structure, which is based on TCP/IP protocol, implementing computer interconnection with the camera system being the client and the control system being the server. The camera system cannot work until the interconnection with the server is set up.

The photographing control thread controls the process of photographing by analyzing the current position of the airplane or the time according to different scheme.

2.2.1.3 Hardware Design

The hardware of the system includes a photographing control board and a power control board. The control program manipulates circuit board by setting the state of the parallel interface. The photo control board controls the camera exposal by triggering the camera shutter with relays, and the power control board controls the power switch of the camera with relays. In order to guarantee the proper working of the switch in a high-vibration condition, aero electric relays instead of common ones are adopted. The parallel interface has a certain voltage output during hardware initialization after the industrial computer starts, but the system requires that the parallel interface should be set after the start of the control program. So a time delay circuit may be added to the hardware circuits to keep the relay off during the starts of the industrial computer. Fig. 2.8 shows the photos of two kinds of circuit boards (a and b) and a photo control device (c).



a b c

Fig. 2.8 Examples of UAV Hardware Components: (a)Photo Control Board; (b)Power Control Board; (c)Photo Control Device

2.2.2 Remote Sensing Ground Monitoring System

The ground monitoring system is developed to provide the pilot, navigator, instrument operator, and mission commander with real-time downloaded image data and navigating data and report sensor working state. With the help of the ground transmission channel of the unmanned airplane, the ground monitoring system displays working states of the on-board devices during the flight as often as possible to ensure the data collection quality.

2.2.2.1 Composition

The ground monitoring system is constituted of four modules: the data acquisition module, data processing module, data display/storage module, and data downloading module, which are illustrated by Fig. 2.9.

During the flight, the ground monitoring system receives and sends the data to the data processing module. Then the valid data is transmitted to the data display/storage module for real-time monitoring and storing of the data for ex-post analysis.

The remote sensing data downloading module downloads the raw image data to computers. The module empties the storage space of the on-board devices and implements consecutive flight without refitting the devices. The four modules of the ground monitoring system are illustrated by Fig. 2.9.

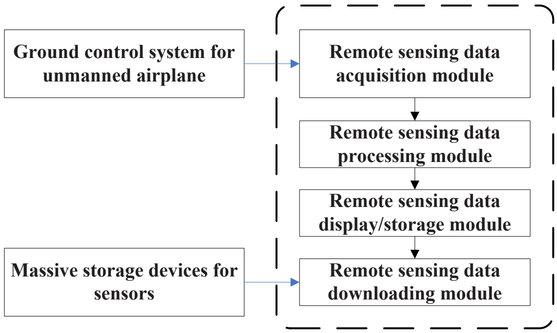


Fig. 2.9 Modules of the ground monitoring system

1) Data Acquisition Module

The function of the remote sensing acquisition module is to receive and send the data to the navigation data including position (longitude, latitude and height), altitude (pitching angle, rolling angle, yaw angle), and the real-time image data to the processing module. The air-to-ground transmission channel of the unmanned airplane packages the remote sensing data, and every data package has a specified mark. By detecting the marks, the data acquisition module sends the specified data to the remote sensing processing module for further processing.

2) Data Processing Module

The function of the remote sensing data processing module is to unpack data. The remote sensing airborne control system firstly marks the navigating path data and image data before transmitting them, then re-packs the data according to the specifications of the navigating task and finally transmits the data to the ground through the air-to-ground transmission channel. The remote sensing data processing module acquires the validated data after removing the navigating task marks. The data is directly sent to the remote sensing data display/storage module.

3) Data Display/Storage Module

The remote sensing data display/storage module displays image data together with the navigating path data corresponding to the image. Simultaneously, this module records the remote sensing data in the database for post playback and analysis, which provides an objective evaluation for the photographing quality. This module is the key part for the ground monitoring system.

4) Data Downloading Module

The remote sensing downloading module is relatively independent. After the unmanned airplane lands and the cabin is opened without changing the load, all the remote sensing data photographed during the flight are downloaded to ground computers. The unmanned airplane can then instantly implement the next task.

2.2.2.2 Software Design

The software of the ground monitoring system is implemented by the following three programs: data acquisition program, data processing program, data display/storage program. The data acquisition program is developed based on pipeline communication. It works in the following procedure: initialize pipeline, set up connection with pipeline server, read data into pipeline, recognize package symbols and send data to the data processing program. The data processing program is in fact an unpacking program which searches marks of the navigating data and image data. The data are then sent to the remote sensing data display/storage module. The communication between data display/storage module and data processing module adopts C/S structure based on TCP/IP.

2.2.3 Multi-Mode Digital Camera System

UAVs are used to carry off-the-shelf light-weight instruments such as consumer digital cameras (Haarbrink and Koers 2006, Shortis *et a.l* 2006), miniature RADAR, passive microwave radiometers, and LiDAR (Vierling 2006, Sugiura *et al.* 2005, Sugiura *et al.* 2007, Martínez-de Dios 2006, Archer *et al.* 2004).

In order to realize the combination of high-resolution, wide view field, multi-spectra and stereo imaging, a set of multi-mode airborne digital cameras (MADC) have been developed. Limited by the actual load of the UAV, we use a small efficient digital camera which has a 4k×4k area array CCD and a focal length of 80mm. The ground resolutions corresponding to different flight altitudes are shown in Table 2.1.

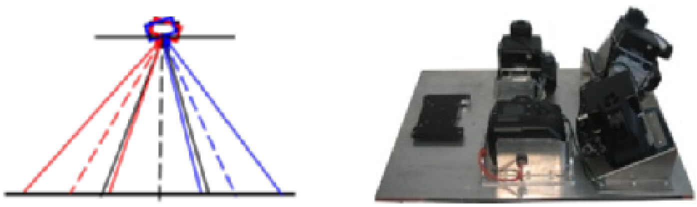
Table 2.1 Ground resolution at different altitudes (focal length=80mm)

Altitude (m)	500	1000	1500	2000	3000	4000	5000	6000	7000
Ground spacing (cm)	5.6	11.2	16.9	22.5	33.8	45.0	56.2	67.5	78.8

Here three cameras are installed on a simple supporting rack. Relative position is designed differently for different modes, such as wide vision field, multi-spectrums. Synchronized triggering of the shutters for the three cameras is performed by the control system. At the same time, the synchronizing pulse is sent to the input interface of the position and orientation system (POS) to sign the time of the photographing moment. After the exposure, image data are transmitted to an industrial computer through and stored in the high speed hard drive. By changing or adjusting the positions and orientations of the three cameras on the simple camera support rack, the following two modes can be composed.

2.2.3.1 High-Efficiency Wide Angle Airborne Digital Imaging Mode

This is one trend of improving the efficiency of airborne photography. This mode aims at implementing high efficiency of digital airborne photogrammetry. This system improves the spatial and geometrical stability of airborne photographing images with the technical innovation based on wide-angle imaging technology, which mainly involves large (wide) area array. The images acquired are actually from three different cameras with certain overlap between each other. The final wide angle field image with larger area is formed from those three images by matching, correcting and splicing. The installation of the three cameras for wide field imaging is shown in Fig. 2.10. The real configuration (Fig. 2.10 b) also has a low resolution color camera.



a b

Fig. 2.10 Wide field of view mode: (a) imaging mode; (b) photograph of the installed cameras

2.2.3.2 Multi Spectrum Remote Sensing Data Acquisition Mode

This digital airborne photographing system shown above can also service as a multi spectrual remote sensing sensor system after reset the geometric relationship of the three cameras. When three cameras photograph the same scene simultaneously, different camera catches different spectral information with a filter.

2.2.4 Automatic Path-Planning System

Aerial photogrammetry based on the airplane platform has a history of 70 to 80 years after the Wright brothers invented the airplane. However, the aerial photography planning (especially the path planning) has long been depending on the planners' manual operations. This method involves much work and can not easily accommodate airborne route change. This traditional planning strategy cannot satisfy the needs in UAV mapping. During the unmanned flight, the mission controllers on the ground have to conduct real-time monitoring on the state of aircrafts and sensors. Thus, a computerized system specially designed for path planning is needed to design flight path automatically, upload the data to the controlling system of unmanned aircrafts and sensors before flight, receive the data from the aircraft in flight, and display on a digital map. This ensures that the mission controllers on the ground can learn about the state of spacecrafts and sensors and control them properly.

Airborne route planning software will provide necessary interface for users to read a vector/raster map or Digital Orthogonal Map (DOM) used for path planning. The data must meet the requirement of geometric precision, and must be transformed to a common geographic reference. The software can enable the technicians to plan the target area interactively and get the optimum airborne route that meets the requirements for remote sensing and airborne surveying. In addition, the technicians can calculate and get several parameters such as the width of strip, degree of overlapping of the image, internal of exposure time, etc. In the end, the related digital aerial file is formed and can be uploaded to the control systems of unmanned aircrafts and sensors to control the aircrafts to fly in the scheduled path and the sensors to get data as designed.

The path-planning system developed in this book includes the following functions: map/image input, flying area planning, and path-planning.

(1) map/image input

It is designed to read vector/raster map or image with geographical coordinates in the format of SHP, GeoTIFF, etc. The input data can be arranged as different layers.

(2) flying area planning

It is an interactive interface by which users can define and modify the flying area on the map or image.

(3) path-planning

It provides the user with visual and non-visual path-planning. The visual path-planning allows the user to plan the path under the background of a map or image which can directly show the relationship between the path and the geographic element. With the non-visual path-planning mode, user can only do it with flying area information without the map and image background.

Fig. 2.11 shows an example of the path-planning system application. This example uses digital map as background. The area with semitransparent mask is the working area and the line indicates the air route. The yellow dot, green dot and red dot represent the preparation point, start point and end point of every air route, respectively.

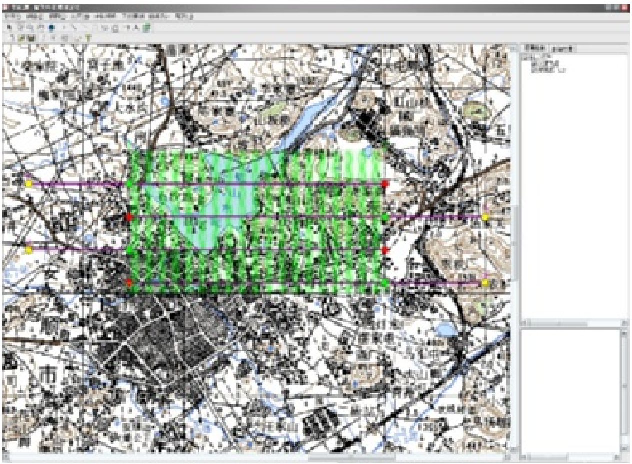


Fig. 2.11 The main interface of the path-planning system

2.3 Experiment of UAV Remote Sensing System

China's first high-end and multi-functional remote sensing based on unmanned aerial vehicle (UAV) made its successful test flight on August 8, 2005 in Anshun City, southwest of China's Guizhou Province. The remote sensing system, jointly developed by Peking University and Guizhou Aviation Industry (Group) Co Ltd, adopts intelligent and high-definition data retrieving technologies. This experiment had three flights (see Table 2.2). The first flights aimed at testing the imaging device on-board. The second time was carried out according to the requirement of photogrammetry, which tested the whole UAV remote sensing system. And, the last one tested the ability of real-time compression and decompression and validated some improvements.

What is more notable is that the resolution has reached 2.25cm at low altitude, with clear identification of heads and tails of ducklings on the farm (Fig. 2.12). Fig. 2.13 shows the air route designed for remotes sensing experimental flight of the UAV. The lines are preset air routes and the dots are the start and end of a line. The area in the box is the working area. An image auto-spliced from images photographed by the high-efficiency wide angle airborne digital imaging mode of MADC is shown by Fig. 2.14.

Table 2.2 General results of experimental flights in August, 2005

	First Flight	**Second Flight**	**Third flight**
Date and time	10:00 , Aug. 8	15:30 , Aug. 18	9:30 , Aug. 24
area	An airport	Anshun City	An airport
weather	cloudy	sunny	cloudy
Relative altitude	200m	1000m	200m，400m
Ground resolution	0.02m	0.10m	0.02m，0.04m
flight velocity	40m/s	40m/s	40m/s
Lens focus	80mm	80mm	80mm
shutter	1/1000s	1/1000s	1/500s
Aperture value	2.8	2.8	2.8
Photograph mode	fixed time interval	fixed position	fixed position
longitudinal overlap	0	54.79%	0
lateral overlap	0	30%	0
Number of images	33	158	48

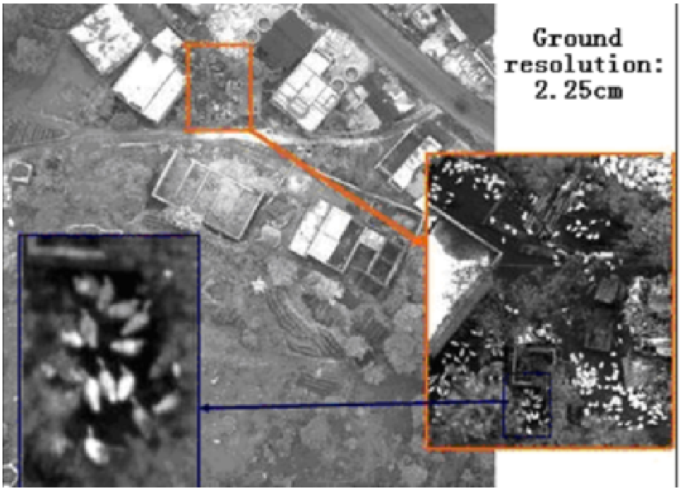


Fig. 2.12 Enlarged images of the duck farm

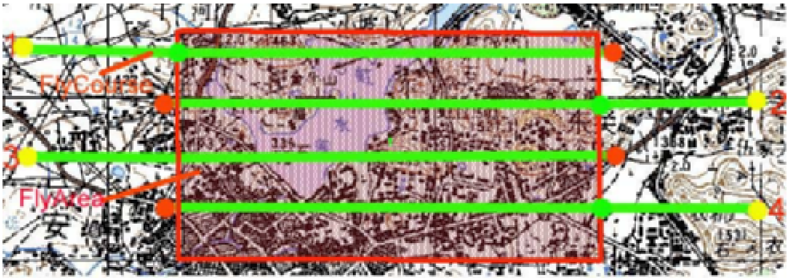


Fig. 2.13 The air route designed for remotes sensing experimental flight of the unmanned aircraft in Anshun, Guizhou Province in 2005

Fig. 2.14 Image auto-spliced by images taken by three parallel high-resolution digital cameras

Fig. 2.15 shows four images acquired at an altitude of 0.2 km by the first experimental flight. Fig. 2.16 gives a part of the real-time mosaic of the snapshots. Fig. 2.17 is an image spliced by images photographed at an altitude of 1km on August 18, 2005.

Generally, this experiment was carried out successfully. In the field of unmanned airborne remote sensing, it firstly adopted integrated, intelligent, and high-resolution spatial data acquisition and other important technologies. The application capability has been qualified, especially in the aspects of reliability, flying altitude, stabilization, navigating precision, operation costs and image acquisition. The experimental flights successfully validate airborne control, ground monitoring, image acquisition and path-planning of the UAV remote sensing system. Even though, the results have shown that UAV is able to be a complement of conventional airborne remote sensing and satellite remote sensing, it still has some problems to be solved, which are listed as follows:

- Complete the path planning system to implement professional task flight of unmanned airplane;
- Study the movement compensation of images to solve the bottleneck problem in high-speed ultra low situation;
- Complete information downloading and compressing/decompressing

functions to provide the basis for the real-time application;

- Minimize the size and weight of digital cameras and remote sensing systems to solve the bottleneck problem of limited payload;
- Develop a complete set of software systems for the automatic processing of UAV remote sensing.

Fig. 2.15 Four images acquired by the UAV system in Anshun City, China

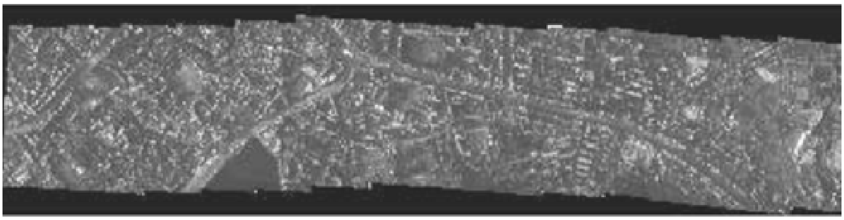


Fig. 2.16 The real-time mosaic of the snapshots

Fig. 2.17 Image spliced by images photographed at an altitude of 1km

2.4 Conclusions

Since UAV has a limited loading capacity, the load must be reasonably designed to reduce the volume, weight, and power consumption while reaching the required performance index. Considering the current development of UAV, UAV remote sensing system should be equipped with one sensor in the early stage. However, the system should have the ability to change according to different sensors quickly (such as optical digital camera, infrared digital camera and SAR). Multiple sensors can be equipped only within the range of the loading capacity of the system. UAV usually has a high precision GPS/INS navigation and positioning device and needs real-time position and altitude data of the station. In order to reduce the weight and power consumption, the positioning data of the remote sensor also shares the GPS/INS data of the UAV. Thus, there is no need to install positioning and altitude measuring equipments any more.

The number of UAV systems used in remote sensing and mapping has been increasing fast in the past years. Many of them are still under research phase, and there are few systems that offer complete solutions to a user. UAVs have given remote sensing a new appeal for scientists and will certainly become the preferred platform for development of remote sensing instruments and applications in the near future when the necessary regulations and techniques are solved.

UAVs are unlikely to replace more conventional remote sensing platforms, but they do offer advantages as means of supplementing conventional field data, especially by providing data that can be coordinated with broad-scale imagery from aircraft and satellite platforms.

Acknowledgments

The authors would like to thank Academician Qingxi Tong, Prof. Shaowen Yang, Qiming Qin, Bing Zhang, Qiming Zeng, Associate Prof. Jian Jiao, Hongying Zhao for their UAV RS research work and contribution to this chapter.

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http://www.springer.com/978-1-4419-0049-4

Geospatial Technology for Earth Observation
Li, D.; Shan, J.; Gong, J. (Eds.)
2009, XIII, 556 p., Hardcover
ISBN: 978-1-4419-0049-4