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A Remote Aerial Robot for Topographic Survey

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***Abstract* - In this paper a seminal system for topographic survey with unmanned aerial robot is presented. The proposed system has demonstrated the feasibility of acquiring initial 3D ground models using active laser range sensors on a low-flying helicopter platform. The robot system consists of a remote control helicopter with a laser sensor and a GPS (global positioning system) for collecting ground point data and a post-processing data sub-system for drawing topographic map. This robot system has many potential applications, such as terrain modeling, structure inspection or climate and weather measurement, etc. The experiment results verify the proposal robot system for topographic survey.**

Index Terms – Unmanned aerial robot, topographic survey, GPS, Active laser ranger sensor

I. Introduction

This paper presents a distance laser sensor and GPS developed for integration with an unmanned aerial vehicle (UVA). The combination of a remote control helicopter with a 3-D mapping system has the potential for use in a variety of applications, and provides a platform for further research and development. Much previous works have been done with active sensing of 3-D structure from both aerial and ground vehicles. Banic, Sizorics and O'neal has flown scanning laser sensors aboard manned helicopters to map the ocean floor[1].Lockheed Martin is developing an airplane based mapping system which uses synthetic aperture radar to build digital elevation maps of very large regions [2]. Ryan Miller and Omead Amidi developed a highly-accurate 3-D perception system which integrated the Carnegie Mellon University (CMU) autonomous helicopter and a scanning laser sensor [3]. Sebastian Thrun, Mark Diel and Dirk Hahnel applied a real-time laser scan matching algorithm to 2-D range data acquired by a remotely controlled helicopter to obtain urban and natural 3-D map terrain [4]. H. Lamela, M. A. Ferreras and A. J. Varo presented an autonomous mobile platform which designed to test the performance of optical and electronic sensors that will be installed in an autonomous Unmanned Aerial Vehicle. This system allows the analysis of the necessary sensors without the risks involved in real flying helicopter through communications between the base station and the mobile vehicle [5]. Many ground vehicles also have utilized laser scanners to scan the regions in front of the vehicle. The ground vehicles can provide highly dense and highly accurate maps, ground vehicles are limited in: the ground has to be traversable by the vehicle itself. Many environments are cluttered with obstacles that are difficult to negotiate. Our interest is in utilizing the advantages of the remote control helicopter of being precisely controllable and its ability to safely fly within close proximity to objects of interest while generating highly dense and highly accurate 3-D models of these objects in possibly remote locations[6][7].

In this paper, a remote control helicopter associated with navigation sensors and other sensors is applied to topographic survey. The significance of the system lies in that it can substitute human efforts where human participation is dangerous, inefficient and/or impossible. The topographic survey described in this paper refers to capturing the three-dimensional information including longitude, latitude and altitude of the ground point and then depicting the accurate 3D structures of terrains. It is effective and useful for many applications. For example, archiving a historical structure or guiding cruise missiles and robotic ground vehicles, all of which need precise 3D information of their surroundings.

Current approaches for topographic survey are primarily as follows: surveying equipment, precision ground scanners, satellites and aerial photogrammmetry and precision airborne laser mapping. Unfortunately, all these practices have their own shortcomings and limitations [11].

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Our topographic survey approach makes use of the combination of a small remote control helicopter with a laser sensor and DGPS equipment which is thought of as a suitable platform for terrain modeling, showing in Fig 1. First, remote control helicopters are highly maneuverable during flight in that they have unique flight capabilities such as hover, vertical take-off/landing, pirouette, and side- slip [9], so that remote control helicopters have the ability to fly along the desired path smoothly and gradually cover the whole desired detected terrain. Second, the small remote control helicopter is capable of flying as closely as possible to the terrain. Therefore, there are few distance details which can not be sensed by the laser sensor. Third, compared to a manned aircraft, the remote control helicopter is much safer for human and economical for terrain modeling. There are still some challenges; however, the DGPS equipment, the laser sensor and the power onboard must be light enough in order to meet the requirement of the relatively restricted takeoff of the small remote control helicopter. Second, engine and rotating rotor blades-induced vibrations during flight may exert a negative influence on modeling precision. In our system, the GPS receivers and the laser sensor are rigidly affixed to a board on the undercarriage. In addition, some shock absorption measures are implemented aiming at minimizing the negative effect due to the vibrations. Third, the equipments onboard must be placed properly to balance the remote control helicopter. We have demonstrated a capable aerial robotic system for terrain modelling which will be described in detail in the following sections.

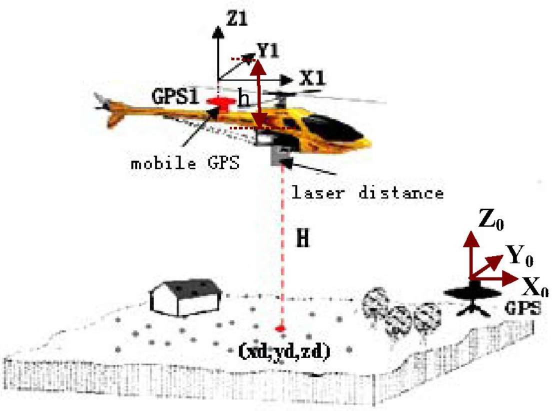

Fig. 1 Outline of remote aerial robot for topographic survey

The contributions of this paper lie in mainly two aspects. First, a terrain modeling system is described. Together with a small remote control helicopter, the integration can capture the initial 3D information of terrains and ultimately build the 3D terrain models. Second, a height detection device is proposed which can help obtain more precise altitude information of the detected terrains.

The paper is organized as follows. In Sect.2, the architecture of the aerial robotic system have been disscussed. The measurement principle and the implementation of the terrain modeling system have been given in sect.3. the experimental results and conclusions have been demonstrated in sect. 4 and 5.

II. REMOTE AERIAL ROBOT SYSTEM FOR TOPOGRAPHIC SURVEY

The aerial robotic system can be divided into two parts according to the difference function during terrain modelling, respectively the hardware including navigation vehicle and the localization detection device and the post-processing software. The aerial robotic hardware system for terrain modelling consists of a small remote helicopter, two suites of carrier phase DGPS equipment, two palm computers, a laser sensor with high precision and a micro-processor with ARM 9. An overview of hard structure is illustrated by Fig. 2.

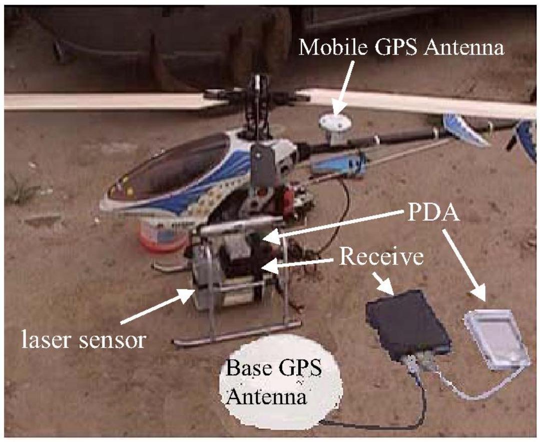

Fig.2 Remote aerial robotic system hardware structure: flying robot and detection devices

A. Navigation vehicle: remote control helicopter

The navigation vehicle is based on the small remote control helicopter Thunder Tiger Raptor 60. Now almost all the components have been upgraded to 90. It has a rotor diameter of 1.54m and is equipped with a blended fuel engine. The maximum takeoff of the navigation vehicle is about 8 kg, consisting of 700 g of fuel, 4.8 kg unladen weight of the helicopter and about 2.5 kg of equipment with small volume and light weight in order to meet the requirement of relatively small takeoff. The operation time of the small remote control helicopter now is about 30 minutes that are considered sufficient enough for performing an experiment.

B. Localization detection device

The navigation vehicle is based on the small remote control helicopter. The localization detection device consists of two identical suites of carrier phase DGPS equipment and a height detection device with an active laser range sensors. The detection devices are same rate of 1 Hz to capture data. One suite of carrier phase DGPS equipment and one palm computer are located at a fixed place on the terrain constituting the master station of the localization detection device, while the other suite of carrier phase DGPS equipment and palm computer are affixed to the undercarriage of the small remote control helicopter constituting the mobile station of the localization detection device.

C. Height detection device

The height detection device is composed of the embedded controller with ARM 9 and the distance laser sensor, namely the laser sensor. The accuracy of the laser sensor plays a significant role to the terrain modelling precision. In principle, the following factors determine the laser sensor's contribution to the precision of the whole terrain modelling system.

1. Laser sensor

Sampling rate: the number of measurements taken each second. Heat dissipation, data processing, and data transfer limitations inside the sensor typically constrain the sampling rate. There are two methods the sensor uses to initiate a measurement. Some sensors allow an external trigger signal to start each measurement, while others continuously measure at a fixed sampling rate [8].

Laser dot size: dependent on the laser spot diameter projected on the target. The farther the distance between a laser sensor and the target, the longer the laser spot diameter, the larger the laser dot size. An important advantage of the large spot size is that the sensor is more robust to small amounts of dirt accumulating on the optics and to small particles in the air, such as light rain or snow. The other significant advantage of the large spot size is that it helps to ensure eye safety .Slow sample rate lasers would employ larger spot sizes to prevent large gaps, while fast sample rate lasers would employ small spot sizes, since the sample density is higher [8].

Critical speed: the maximum speed relative to the target beyond which the laser sensor would not be capable of receiving the reflected laser beam. Then the range value at that moment would be lost which might bring about the inaccuracy of terrain modeling.

We chose the DIMETIX laser sensor as our distance laser sensor. The laser sensor has a maximum measuring range of 30m on natural surfaces and 200m on reflecting target plates. Its measuring accuracy is ±3mm and weighs 630g in order to meet the limited takeoff requirement of the small remote control helicopter. Once the laser sensor is triggered by an external signal, it takes continuous measurement at a fixed sampling rate. Although the sampling rate is able to be up to 3Hz, it was preset to 1Hz considering consistency with the frequency of GPS receivers and available flying speed of the remote control helicopter. The diameter of laser spot at target is 60mm at a distance of 100m [12].

2. Embedded controller with ARM 9

In order to control the active laser sensor and store the height between the fly robot and the ground every second, we develop an embedded controller with ARM9 micro-processor. The CPU frequency is 203MHz. There are 2M RAM and 64M ROM onboard. Three RS232 series ports and two USB ports have been extended. The laser sensor connect to Embedded controller with RS232 port, and other one of the RS232 port can connect to PC or portable computer to download the embedded control program or debug the laser device. The embedded operation system is the min-Linux and the control program must edit in the cross edit environment: arm-gcc. The embedded controller as an onboard flight computer not only instructs the laser sensor to turn on and measure the vertical height at the rate of 1Hz, but also stores the height data automatically into a prescribed document according to a predetermined frequency which is configured to once per second in the experiment.

D. Post-processing software

The post-processing software is the commercial software: GrafNav which will switch transparently from STATIC to KINEMATIC processing, as long as the static/kinematics flag is set properly in the GPB raw GPS data file. A fixed static solution is available for static initialization on short or medium length baselines. A float static solution is available for long or noisy baselines. In this paper we use GrafNav read the master station and mobile station GPS data into PC and translate those date to coordinates in the earth frame. The origin of earth frame is the earth's core. The post-processing software can convert the master station position to (X_0,Y_0,Z_0), the mobile station position to (X_1,Y_1,Z_1).

III. MEASUREMENT

A Measurement Principle

The fundamental measurement principle of the aerial robotic system for 3D terrain detection basically attributes to the master station and the mobile station, which have been presented in Sect. 2 and the laser sensor as well. Fig. 3 demonstrates a specific flow of the measurement principle for terrain modeling.

The master station, located at a fixed place on the ground, is considered as the datum mark of the whole system. It is responsible for registering the real time 3D coordinates of datum mark including longitude, latitude and altitude information (X_0, Y_0, Z_0). At the same time, the mobile station affixed to the undercarriage of the small remote control helicopter memorizes the helicopter's real time position coordinates (X_1,Y_1,Z_1), and the laser sensor detects the distances to the terrains symbolized by H at the same rate with two stations. With the purpose of acquiring more accurate navigation trajectory of the helicopter, a difference algorithm is introduced to the system. The algorithm processes the data from both stations and obtains the precise navigation trajectory coordinates (X', Y', Z') with respect to the datum mark. But the coordinates (X', Y', Z') are not the final result we need. Three dimensional coordinates (X_d, Y_d, Z_d) of the detected terrains covered by the helicopter are ultimately retrieved by mathematical operations among Z', H, and the vertical height h from the fuselage where the GPS antenna is located to the undercarriage, which is a constant parameter of the remote control helicopter. The relationship is $Z_d= Z'-(H+ h)$. Then, the location 3D position (X_d, Y_d, Z_d) in the master station frame is:

$$
\begin{aligned}
X_d &= X_1 - X_0 \\
Y_d &= Y_1 - Y_0 \\
Z_d &= Z_1 - Z_0 - (H+ h)
\end{aligned}
\tag{1}
$$

B. Terrain measurement process

The small remote control helicopter carries the equipment of height detection device and the mobile station of localization detection device hovering in the air. Currently, the small remote control helicopter is controlled by means of remote operation. During the course of flight, the palm computers with Win CE applications, both on the terrain and on the undercarriage, have the ability to automatically read, display and store the satellite data coming from the GPS receivers at the rate of 1Hz, including the number of the satellites which have transmitted satellite signal to the GPS antennae and position information as well. Technically speaking, the data kept in the palm computer of the mobile performing an experiment.

However, the data here is not accurate enough. That's why two suites of carrier phase DGPS equipment have been used. When the number of satellites is less than four, the palm computers won't record the satellite data. Meanwhile, the embedded-controller measures the vertical height and stores the height data at the rate of 1Hz automatically. Because there is timing system inside palm computers and we can also take down the exact time when the laser sensor is triggered by the external command and starts taking measurement, the system-wide temporal registration can be implemented so that we can integrate the distance laser sensor data with the 3D data from the GPS receivers to achieve accurate terrain modelling.

After the fight, the data in palm computers and the micro-processor is attainable. Then the post-processing software makes use of the difference algorithm to deal with the data from two palm computers and obtains more precise longitude, latitude and altitude information of the GPS antenna of the mobile station which is also the information of corresponding points on the detected terrain.

Moreover, the vertical distance from the undercarriage of the small remote control helicopter where the laser sensor is located to the corresponding points on the terrain has already known by virtue of the data in the micro-processor. And the vertical height from the fuselage, the location of the GPS antenna to the undercarriage is a constant parameter of the remote control helicopter. In addition, the data both in palm computers and the ARM micro-processor is synchronous in time and frequency. Therefore, the altitude of the detected terrain can be figured out through simple subtractions. Till now, all the three-dimensional information of the detected terrain has been known and the three-dimensional models of the detected terrain can be built by expressions (1).

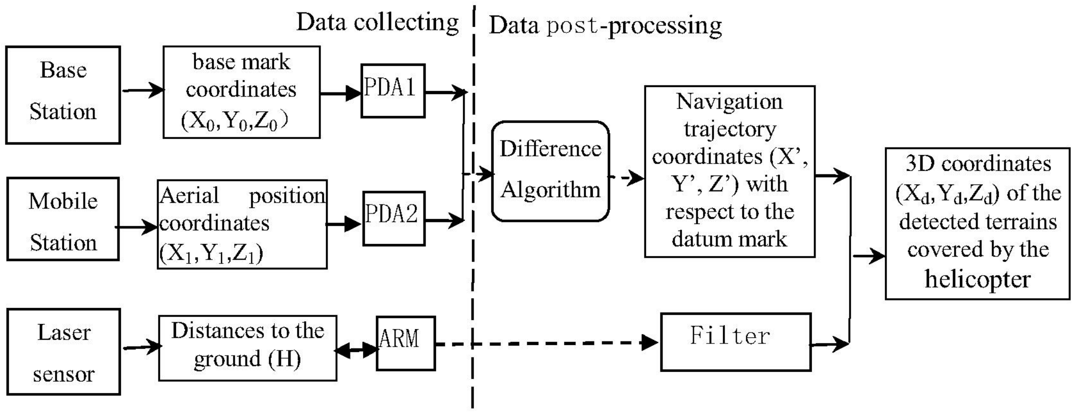

Fig.3 Fundamental principle of aerial robotic system for topographic survey

IV. EXPERIMENT

In this section, we present the results of several experiments the aerial robotic system has carried out in the real world. It has been proved that there are more challenges to terrain modelling under practical circumstances. Weather condition, temperature and some unexpected factors would affect the successful implementation of the aerial robotic system.

Fig. 4 is a 2D profile of a playground processed by the difference algorithm, the red point is the mobile station and green is the exact position of the base station.The accurate longitude and latitude information is obtained by the difference algorithm which processes the satellite data received by DGPS equipment from both the master station and the mobile station. Several experiments have proved that the global accuracy of the system for terrain modelling is at least 0.1 meters.

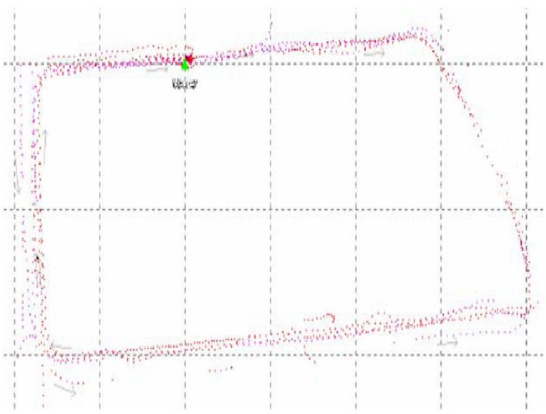

Fig.4 A playground's 2D profile processed by GPS difference algorithm

Fig. 5 shows the result of the three-dimensional model of the detected terrain by aerial robotic system in an experiment where the small remote control helicopter hovered above a car 10m and the car size is 3885 mm×1665 mm×1695 mm.hovered above a car 10m and the car size is 3885 mm×1665 mm×1695 mm. Fig 5(a) is the real photo of the car. The global accuracy of the aerial robotic system for terrain modelling is at least 0.48 meters where is the car glass of reflecting a little laser. The global accuracy of the other size for car modelling is at least 0.1 meters. Fig.5 (b) is the 3D model of the car.

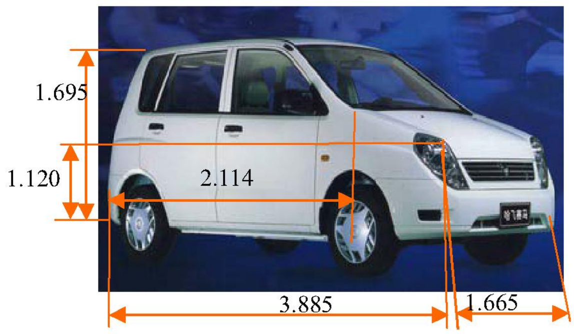

Fig.5 (a) Real photo of the car

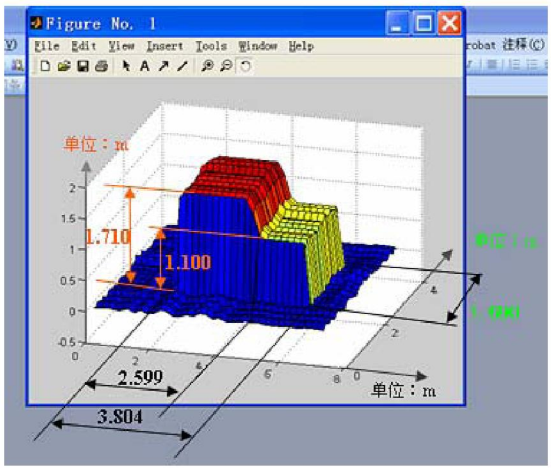

Fig.5 (b) 3D model of the car built by aerial robotic system

V. CONCLUSIONS

In this paper, we have demonstrated a capable aerial robotic system for topographic survey by integrating the small remote control helicopter with a highly accurate laser sensor and two suites of DGPS equipment. There are two primary accomplishments in this work. One is that an aerial robotic system with the purpose of terrain modelling is constructed. The other one is that a height detection device is introduced which helps accomplish the precise altitude information. And the experiment results verify the proposal robot system for topographic survey

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