Practical and Potential Applications of an ~~Embedded Automatic Control Computer System in an~~ Unmanned Airship based on Automatic Control - Embedded Computer System Design~~Reliability and Availability Analysis and Design~~

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Abstract

Unmanned Airship is useful and applicable for a variety of fields especially in resource exploration and environmental monitoring. This measure enhances the flexibility, on-demand supply and reasonable cost. This is a fruitful approach to meet actual needs. In this paper, we propose an embedded automatic ~~Unmanned Airship~~computer system architecture design for an Unmanned Airship in terms of hardware system, software system and automatic control algorithm perspectives. ~~and perform reliability and availability analysis. Based on that, an embedded computer system is presented in term of hardware and software perspective.~~ At last, we discuss the practical results in resource exploration and environmental monitoring that we have achieved as well as other potential applications of the Unmanned Airship.

1. Introduction

An Unmanned Airship ~~(UA)~~ is an autonomous integrated system without any man's intervention using a big size balloon. It is very useful in the "D-Cube" missions, i.e. missions with Dangerous, Dirty or Dull [2] concerns. With a lot of valuable advantages such as high reliability, availability and stability ~~as well as~~and other physical characteristics, UA proves its capability to be exploited in a variety of practical applications in military as well as in civilian segments. Among its worthy applications, resources exploration and environmental monitoring have been rising as popular applications in nations especially in developing countries. However, most of the

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applications cited above require maneuverable low altitude, low speed, and airborne data gathering platform. ~~Moreover, it is critical to design a system with a good reliability and stability.~~ In this context, we are currently developing a cooperative project on an Unmanned Airship with our concerns focusing on resources exploration and environmental monitoring. ~~Reliability, availability and stability are also our theoretical concerns.~~ In this paper, we present our design, analysis and proposal as well as practical results and potential applications of an Unmanned Airship. The paper contents are chronologically presented as follows. ~~in the following order:~~ Section 1 is Introduction as above. Section 2 focuses on architecture design of the embedded computer system. We present our designs on hardware system, flight software system and our construction and discussion on automatic control and guidance algorithms. Later on, in section 3 we present our practical achievements and discuss potential applications of the Airship.~~architecture design and analysis (Section II), reliable embedded computer system (Section III), practical results and potential applications (Section IV),~~ At last, we conclude with some conclusions in section 4~~ (Section V)~~, acknowledgement and references.

2. Architecture Design ~~and Analysis~~

2.1. Specification

~~2.1.~~ For a short introduction, we list down the main information and common physical characteristics of the Airship in a compact form as in the Table 1.

Table 1. Airship specification

General mechanical configuration	
Length	15m
Diameter	3.8m
Height (H)	4.9m
Volume	90m3
Weight	81kg
Payload	9kg
Gas	Helium
Flight speed	0~40km/h
Maximum speed	75km/h
Flight altitude	0~450m
Engine specification	72cc5.5hp×2 two strokes
Maximum rotation of engine	110◦
Fuel	Gasoline or Oil 25:1
Flight time (One time fuel injection)	4hours
Control surfaces	FUTABA FF8 8ch
Maximum operable wind speed	8m/sec
Main hardware configuration	
FCC (Flight Control Computer)	Development kit: Eddy DK v2.1 (System Base Company) Sub-CPU: ARM chips (Atmel~~Ublox~~ Company)
Inertial measurement unit (IMU)	Crossbow NAV440 (low drift MEMS-based inertial sensors with GPS aiding)
Air/Pressure sensors system	Air data boom
RF (Radio Frequency) Modem	Products of Maxstream Company (FHSS-Frequency Hopping Spread Spectrum)

2.2. Embedded Hardware System Architecture

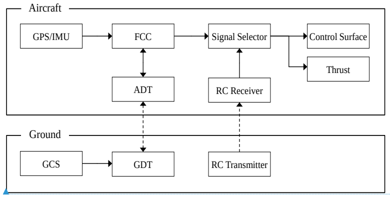

Figure 1. ~~(Figure 1)~~Outlook Architecture of ~~Airship~~Propose Airship System

Figure 1 presents the whole view of the Airship system including Airship segment and Ground Station segment. Each of blocks ~~shown in the figure~~ represents the sub-components. The reason the above outlook is presented is that there is a consistent dependence between Airship and Ground Station in order to accomplish the common missions. The flight system is divided into 7 sub-components as follows.

1. *GPS/IMU* (Global Positioning System/Inertial Measurement Unit): measures physical parameters of Airship including attitude, position and direction.
2. *FCC* (Flight Control Computer): communicates with Ground Station to receive commands or transmit different kinds of data/information of Airship, collects information/data from sensors or measuring devices including GPS/IMU to generate flight control signals in order to control and operate smoothly the whole embedded system. This is the main control center of Airship as its “brain”.
3. *ADT* (Air Data Terminal): communicates and directly interacts with Ground Station in order to

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receive and transmit commands and data in a duplex way.

4. *Signal Selector*: chooses one of two control modes which ~~is~~are automatic or manual depending on the circumstances of the flight.

5. *Receiver (RC)*: manually receives control signals from Ground Station.

6. *Control Surface:* this is a subcomponent used to control the steering surface/plane in order to adjust the attitude, altitude, direction of the Airship. There are 5 different configurations including Aileron 1 and 2, Elevator, Rudder, and Throttle.

7. *Thrust*: Airship's thrust control subcomponent.

Likewise, the Ground Station is also divided in to 3 subcomponents as follows:

a) *GCS* (Ground Control System): display the real-time state of the whole Airship system as well as interact with End-User in order to receive and serve his commands.

b) *GDT* (Ground Data Terminal): is the port of Ground Station in the communication with Airship

c) *RC Transmitter:* receives manual control commands input from user.

8. Arrows in Figure 1 connecting subcomponents represent the interfaces between components. In the automatic flight mode, commands and data can be sent from Ground Station via GCS. In other side, commands also can be sent manually through RC Transmitter. The commands from GCS are transmitted wirelessly through GDT to ADT then delivered to FCC. Inversely, FCC generates collected data/information about the operational states of whole Airship system, and then it transmits wirelessly to Ground Station through ADT, received by GDT and later on displayed on GCS. Under the user's commands, FCC collects signals generated from GPS/IMU about real-time information on Airship attitude and location. The user's control commands are also sent to Airship received by RC Receiver through RC Transmitter. Automatic control commands coming from FCC and manual control commands coming from RC Receiver are selected by Control Signal Selector and transmitted to Control Surface and Thrust simultaneously after that in order to operate and adjust the steering wings and motors following the commands of user or planned route.

~~As in the Table 4, the steady state availability is~~

~~**Figure 1.**~~ ~~**System Architecture of Automatic**~~

Figure 2. Autopilot with survey equipment

The system configuration with survey equipment is show~~s~~n ~~as~~ in the Figure~~.~~ ~~6~~2 in which the survey equipment is added on the main CPU. Through this architecture, we can add on/~~ or ~~remove ~~whatever~~any kind of survey equipment to/from the system without affection to whole system architecture. This configuration provides ~~is showed as the~~ good flexibility and expendability properties of the Airship system. ~~of the airship system architecture.~~

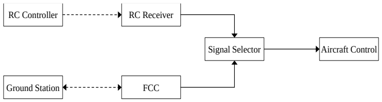

Figure 3. Autonomous and Manual Control of Proposed System

In general, the Unmanned Airship is equipped autonomous control techniques such as waypoint navigation, introduced in section 2.4, in order to accomplish its missions on the air. The design grants a certain level of autonomy to the Airship. But when we need fine-grained control in the cases of take-off, landing, scanning flight mode, crash, failure mode, and other critical cases, etc., manually control is necessary. In other face, if we put these two control measures separate, manual control mode is considered as a kind of backup control system. Figure 3 shows clearly backup advantage to enhance the reliability of control system which is a critical concern in system design. The control system includes two different control input sources. The first source is Ground Station software system which communicates with the Airship in a duplex way. It sends the control information including missions, trajectory, etc. to the Airship. In turn, FCC in the Airship receives the above information via ADT, processes them and sends control signals to Signal Selector. Through this channel, the Airship's operation is in full autonomy mode. The second source is RC Controller. This source provides a manual control mode. In this case, User uses RC Controller to send his commands directly

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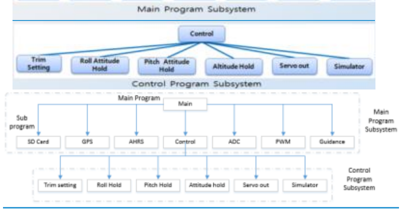
to the Airship. The commands are received by RC Receiver on the Airship and send to Signal Selector to adjust the movements and operations of the Airship right away. If the first automatic channel is in the failure state because of FCC failure, the second manual channel takes over control of the entire system as a backup system to ensure continuous operation of the Airship. In other aspects, this way also enhances the reliability of the Airship system to accomplish the final mission. However, in the case that Signal Selector undergoes any failure; the entire system is in Failure state because of control system failure.

~~119.1.~~4.1. Flight ~~Embedded~~ Software Architecture

The flight embedded software is arranged and organized in program, subprogram or modules. The main program consists of 7 other subprograms including SD Card, GPS, AHRS, ADC, PWM, Control, and Guidance as in the Figure~~.~~ ~~7~~4.



~~Figure 2.~~ Figure 4. Autopilot software structure

SD Card, GPS, AHRS are the programs communicating with peripheral devices including SD Card, GPS instruments, IMU sensors, etc. to acquire physical information of Airship system. ADC is the analog to digital converter program. PWM is the pulse-width~~se~~ modulation program. Guidance is the heading program to guide the airship fly following the track in the mission. The Control subprogram is described in lower layer as follows. It consists of Trim Setting subprogram used to configure the Trim tabs of wings. Roll Attitude Hold, Pitch Attitude Hold and Altitude Hold are the subprograms holding the angles Roll and Pitch and the altitude of the airship. Servo Out is the subprogram controlling and monitoring the Servo motor. It receives the pulse-width signals and deploys on the motor. And the last one is Simulator used as an automatic demonstration.

4.2. Automatic Control Aerodynamics and Algorithms

This subsection focuses on introducing the theory and algorithms of automatic control for our Airship. Attitude determination and control are always the main points in any autonomous physical system in term of theory and practical embedded control software. It is not an exception for our Airship. Besides, guidance and navigation are also another important concern in order to accomplish any planned mission.

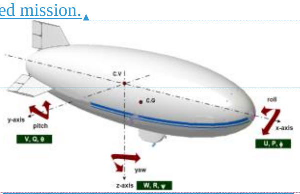


Figure 5. Aerodynamic Coordinate System

Figure 5 shows the aerodynamic coordinate system of the Airship. In order to simplify mathematical models of the Airship aerodynamics and control, we use the Roll-Pitch-Yaw angles to represent the Airship attitude. The position of Airship is determined by the position of the coordinate system Oxyz attached to Airship at the center of volume (c.v). Because of gas leaking, the mass of Airship keeps decreasing gradually and hence the center of gravity (c.g) also keeps changing gradually. Inversely, the big size and volume of Airship leads to the almost unchanged center of volume. We have to choose c.v as the origin of this Cartesian coordinate system. The parameters (v, w, and u) are called linear velocities corresponding to the linear displacement X, Y, Z along with the axes Ox, Oy, Oz. Similarly, the parameters (q, r, and p) are called as angular velocities corresponding to the angular changes (θ, ψ, ϕ) around the above axes.

In small perturbations, the trim terms sum to zero. Hence, in state space form the linearized longitudinal equations of motions are introduced in (1). With a big size, Airship is normally considered as a rigid object floating in the air. Regard to that aspect, the first-order differential equations are employed for simplification and control efficiency. **x** is aerodynamic parameters matrix which consists

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Formatted: Font: 9.5 pt, English (United States), Not Expanded by / Condensed by of parameters representing the Airship aerodynamics and physical characteristics. These parameters in the above matrix are needed to be adjusted automatically to accomplish the planned missions. **u** is control matrix which consists of control parameters. These parameters are input for the control equations and adjusted by the actuators or motors. The control theory of actuators or motors is not our concern here. **m** is a mass matrix which consists of real and virtual mass parameters of the Airship. **a** and **b** are constant matrixes shrinked after linearization.

$$\mathrm{m}\dot{\mathrm{x}} = \mathrm{ax} + \mathrm{bu} \tag{1}$$

$$\mathbf{x}^T = \begin{bmatrix} u & w & q & \theta \end{bmatrix} \; \mathbf{u}^T = \begin{bmatrix} \delta_e & \delta_r \end{bmatrix} \tag{2}$$

$$\mathbf{m} = \begin{bmatrix} m_x & 0 & \left(ma_z - \overset{\circ}{X}_{\dot q}\right) & 0 \\ 0 & m_z & -\left(ma_x + \overset{\circ}{Z}_{\dot q}\right) & 0 \\ \left(ma_z - \overset{\circ}{M}_{\dot u}\right) & -\left(ma_x + \overset{\circ}{M}_{\dot w}\right) & J_y & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

$$\mathbf{b} = \begin{bmatrix} \overset{\circ}{X}_\delta & \overset{\circ}{X}_t \\ \overset{\circ}{Z}_\delta & 0 \\ \overset{\circ}{M}_\delta & \overset{\circ}{M}_t \\ 0 & 0 \end{bmatrix} \tag{4}$$

$$\mathbf{a} = \begin{bmatrix} \overset{\circ}{X}_u & \overset{\circ}{X}_w & \left(\overset{\circ}{X}_q - m_z W_e\right) & -\left(mg - B\right)\cos\theta_e \\ \overset{\circ}{Z}_u & \overset{\circ}{Z}_w & \left(\overset{\circ}{Z}_q + m_x U_e\right) & -\left(mg - B\right)\sin\theta_e \\ \overset{\circ}{M}_u & \overset{\circ}{M}_w & \left(\overset{\circ}{M}_q - ma_x U_e - ma_z W_e\right) & \left\{\left(mga_z + Bb_z\right)\cos\theta_e - \left(mga_x + Bb_x\right)\sin\theta_e\right\} \\ 0 & 0 & 1 & 0 \end{bmatrix} \tag{5}$$

After inversing **m**, the above equations become the classical control state form as in (6)

$$\dot{\mathbf{x}} = \mathbf{Ax} + \mathbf{Bu} \tag{6}$$

$$\mathbf{A} = \mathbf{m}^{-1}\mathbf{a} = \begin{bmatrix} x_u & x_w & x_q & x_\theta \\ z_u & z_w & z_q & z_\theta \\ m_u & m_w & m_q & m_\theta \\ 0 & 0 & 1 & 0 \end{bmatrix} \tag{7}$$

$$\mathbf{B} = \mathbf{m}^{-1}\mathbf{b} = \begin{bmatrix} x_\delta & x_t \\ z_\delta & 0 \\ m_\delta & m_t \\ 0 & 0 \end{bmatrix}$$

Similarly, we derive to linearized lateral equations of motion in small-perturbations case as in (8) to (13).

$$\mathrm{m}\dot{\mathrm{x}} = \mathrm{ax} + \mathrm{bu} \tag{8}$$

$$\mathbf{x}^T = \begin{bmatrix} v & p & r & \phi \end{bmatrix} \; \mathbf{u}^T = \begin{bmatrix} \delta_r \end{bmatrix} \tag{9}$$

$$\mathbf{m} = \begin{bmatrix} m_y & -\left(ma_z + \overset{\circ}{Y}_{\dot p}\right) & \left(ma_x - \overset{\circ}{Y}_{\dot r}\right) & 0 \\ -\left(ma_z + \overset{\circ}{L}_{\dot v}\right) & J_x & -J_{xz} & 0 \\ \left(ma_x - \overset{\circ}{N}_{\dot v}\right) & -J_{xz} & J_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{10}$$

$$\mathbf{b} = \begin{bmatrix} \overset{\circ}{Y}_\delta \\ 0 \\ \overset{\circ}{N}_\delta \\ 0 \end{bmatrix} \tag{11}$$

$$\mathbf{a} = \begin{bmatrix} \overset{\circ}{Y}_v & \left(\overset{\circ}{Y}_p + m_z W_e\right) & \left(\overset{\circ}{Y}_r - m_x U_e\right) & \left(mg - B\right)\cos\theta_e \\ \overset{\circ}{L}_v & \left(\overset{\circ}{L}_p - ma_z W_e\right) & \left(\overset{\circ}{L}_r + ma_z U_e\right) & -\left(mga_z + Bb_z\right)\cos\theta_e \\ \overset{\circ}{N}_v & \left(\overset{\circ}{N}_p + ma_x W_e\right) & \left(\overset{\circ}{N}_r - ma_x U_e\right) & \left(mga_x + Bb_x\right)\cos\theta_e \\ 0 & 1 & 0 & 0 \end{bmatrix} \tag{12}$$

$$\dot{\mathbf{x}} = \mathbf{Ax} + \mathbf{Bu}$$

$$\mathbf{A} = \mathbf{m}^{-1}\mathbf{a} = \begin{bmatrix} y_v & y_p & y_r & y_\phi \\ l_u & l_p & l_r & l_\phi \\ n_u & n_p & n_r & n_\phi \\ 0 & 0 & 1 & 0 \end{bmatrix} \; \mathbf{B} = \mathbf{m}^{-1}\mathbf{b} = \begin{bmatrix} y_\delta \\ 0 \\ n_\delta \\ 0 \end{bmatrix} \tag{13}$$

The linearized algebraic equations (6) and (13) are used to control the airship by the control input vector **u** composed of control surfaces. The control surfaces are constituted by elevators and rudders respectively depicted in Figure 6.

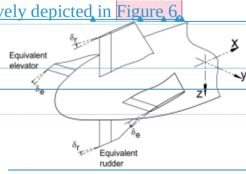

Figure 6. Notation of Control Surfaces

In this paper, the complicated field on motor/engine automatic control is not going to be presented. It is supposed that in the automatic control mode, airship does not change extremely its altitude therefore the control concerned here is

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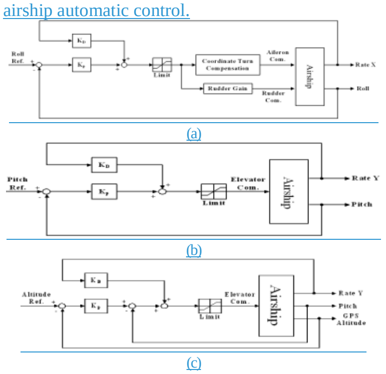
automatically changing the operational angles of rudder and elevator for stabilization and guidance. In practice, Yaw angle is not necessary to control because two engines fixed on gondola are able to spin around the Oz axis to provide thrust vectors. Both these engines can operate independently/dependently. In the case of favorable test environment without wind, the Yaw angle changes not so much as the airship is in automatic stabilization due to the huge body shape. Therefore we ignore controlling the Yaw angle and just consider it in guidance to change the trajectory by the measure of using another motor mounted at the airship nose to perform rotation about Oz axis. Possessing several proses such as fast response, damping improvement, maximum overshoot reduction, rise and settling time reduction, increasing bandwidth, gain and phase margin improvement, PD controller is very appropriate for airship automatic control.



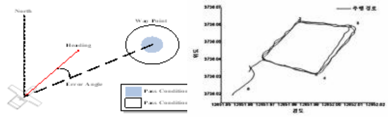
(a)

(b)

(c)

Figure 7. Automatic Attitude Control Algorithm
(a) Roll angle control algorithm (b) Pitch angle control algorithm (c) Altitude control algorithm

In order to control the Roll angle, we need to control the Rudder to change the airship's inclination in its vertical plane. By that way, we can stabilize the airship around the axis X (principal axis along with the airship body). However, this change also causes the imbalance and direction change around the vertical axis; hence we employ Coordinate Turn Compensation to compensate the control signal applied on the Aileron of the control wings. By that measure, the airship can regain its balance. The angle Yaw will be compared with the Yaw reference to calculate the difference. This difference is the input for Proportional control (P). The rate around X axis is collected to be the input for Differential control (D). The above explanation is briefly illustrated as in the Figure 7(a). The Figure 7(b) illustrates the principle of Pitch control. In this case, we need to control the Elevator to change the rising up or falling down of the airship head in the vertical plane. Because the Pitch change does not affect to the balance or direction, we don't need to control other factors. Similar to Roll control, Pitch angle and the rate around axis Y are measured to be the input parameters of PD controller. In the case of altitude control as briefly illustrated in the Figure 7(c), the control law is almost same as Pitch control. However, we need to change the reference of control process to the Altitude Ref. GPS altitude is also collected to be one of the input parameters and compared with the altitude ref. to compute the difference to be the input of Proportional control (P).



(a) (b)

Figure 8. Waypoint Navigation Algorithm
(a) The principle of Waypoint algorithm (b) Derived results guided by Waypoint algorithm

In essence, guidance is similar to Yaw control. However, the above control algorithms of Pitch and Roll are used to stabilize the airship attitude during observation flight to obtain the stable and reliable data from specific sensors. A motor is mounted on the airship nose, it directly generates moment around the axis Z to change the Yaw angle or in other words to change the airship direction. The principle here is controlling the above motor in order to the angle error between the direction of movement measured using GPS device and the line linking current position of the airship to the way-point on the given path gradually converges. The feedback control algorithm is applied for this. This law is illustrated as in Figure 8(a). In the Figure 8(b), the programmatic results of guidance following a given square-shape trajectory are shown.

~~121.~~5. Practical Results and Potential Applications

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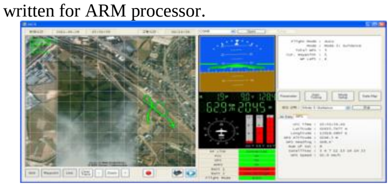
In this section, some featured results are briefly demonstrated. The following photos in Figure~~.~~ ~~11~~9 show the real embedded system and the practical airship in testing.

Figure 9. System configuration of automatic flight test and practical test in Uranium~~Zinc~~ Mine Site

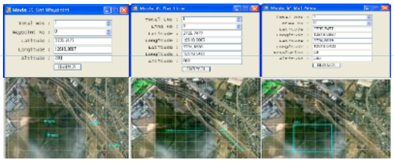
For embedded software development, we used Eclipse IDE to code for automatic flight control computer. The source codes are all in C language written for ARM processor.



~~Figure 3.~~ Figure 10. Automatic flight control, ground control software with additional functionality

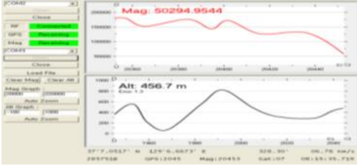
The Figure~~.~~ ~~12~~10 illustrates the GCS software. added a function that displays the image of exploration area and the trajectory that the airship has been following. The middle region in this user interface, we express all real-time aerodynamic information about the flight such as attitude, velocity, altitude, direction, target, battery energy, communication state etc. And at the right side region, we create a user manual to handle system configuration for the flight.

There are 3 modes we need to complete before flight. Set Waypoint is the mode that set the points on trajectory so that the airship can trail those points. Set Line is the mode that set the trajectory line. And Set Area is the mode that set the area in which the airship flies. In Figure~~.~~ 11~~3~~, the modes of operation for configuration and their results on the realistic maps are expressed.

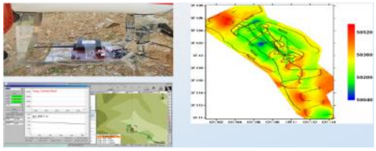


~~Figure 4.~~ Figure 11. Trajectory setting interface (Waypoint, Line and Area) and Results on realistic maps

The Figure~~.~~ ~~14~~12 illustrates the practical results resource exploration real-time transmitted back from airship in flight. Those are the magnetic intensity change in the exploration area and the altitude change by time. In this figure, left side region is the control panel. It receives data arriving to COM port of control computer in GCS. It also indicates whether signals are receiving or not based on the ping mechanism. On the right side region, data of magnetic field and altitude are graphically and real-time plotted.



~~Figure 5.~~ Figure 12. Auto zooms in/out data acquisition with additional functionalities



~~Figure 6.~~ Figure 13. Experiment on Zince Mine Site

In ~~the~~ Figure~~.~~ 1~~5~~3, we demonstrate a data prototype of survey equipment. The magnetic data is also illustrated in the spectral graph. It shows the magnetic density change in gradient.

The recent test is shown in the Figure~~.~~ 1~~6~~4. The exploration was performed in the highland area to find out how strong the magnetic field is there. In the advantage of acquired data, we can explore natural resources. A set of waypoints were made in order to create parallel lines on the high-view photo as a mesh. This mesh forms the trajectory with the purpose of covering ~~as much as possible~~ the

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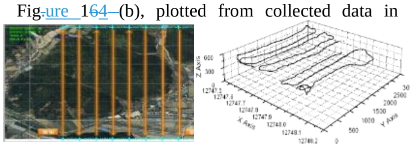
as possible, illustrated in Fig~~.~~ure 1~~6~~4 (a). A 3D real trajectory along with the given paths is shown in Fig~~.~~ure 1~~6~~4 (b), plotted from collected data in



(a) (b)

~~Figure 7.~~ Figure 14. **Practical experiment in Zince Mine Site**
(a) Parallel trajectories (b) ~~The r~~Real trajectory along with the given paths

From the Fig~~.~~ure 1~~6~~4 (b), the practical trajectory follows hard after the given one. It convinces that the process of attitude control during flight, the errors in operation and computation are acceptable. Hence, the stabilization of the airship is good enough for collecting data.

~~121.6.~~5.2. Environmental Monitoring

With different outstanding advantages such as reliability and availability in operation as well as stability in collecting data, Unmanned Airship has a lot of useful applications beside the common above application on resource exploration. One of these meaningful applications we have been in progress with our Airship is environmental monitoring. In this practical application, the Airship plays different roles for different purposes. In Figure 15, the Airship is used as a communication relay in an environmental monitoring system. In this case, the Airship plays the main role to monitor the forest as well as water sources. All the metadata/information of forest and water resources is collected by the Ubiquitous Sensor Network (USN) in which the sensors to be used would depend upon the type of data desired and different sensors could be installed for different missions. Then it is transmitted to the Airship in real-time and aggregated at LEO Satellite node using a store-forward mechanism like Delay/Disruption Tolerant Networking. The data may be preprocessed at Airship node or Satellite node in the scale of different areas or regions as well as for high-speed transmission. At the end, the processed data is transmitted to the Environmental Monitoring Head Quarters of the country or others for investigation, supervision and management.

~~Figure 8.~~ Figure 15. **Development concept of Satellite, Unmanned Airship, USN integration for operations and data fusion technology**

With acceptable stability and low-speed or flexibly operable speed of flying as well as flexible movement control accompanying with the very large coverage of wireless communication, the Airship has been utilized in many different environment monitoring missions especially in urban areas. One of those applications is Atmospheric composition and air pollution monitoring at high altitude. In Figure 16, the Airship is monitoring and measuring atmospheric composition in an urban area within the audience's visibility automatically in an experimental demonstration. Special sensors and measurement devices are carried on the Airship in order to analyze the air composition to check out the level of environmental pollution in that urban area. The Airship is roaming around the area in many days to accomplish the environmental monitoring mission.

~~Figure 9.~~ Figure 16. **Automatic Flight Demonstration in an Environment Moritoring mission**

~~121.7.~~5.3. Potential Applications

There are a lot of useful and meaningful applications rising day by day exploiting Unmanned Airship. To date, most of UA missions have been for military in nature. There has been relatively little civilian use of UA. Although it is either military or civilian use, UA still shows off many worthy advantages. The potential missions for Unmanned Airship that we are attempted to pursuit include weather reconnaissance, pollution monitoring, navigation aid for higher accuracy in GPS system, forest fire detection, land mine detection, civilian or military mapping, on-site

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inspection support, border monitoring, especially disaster response and GIS system.

6. Conclusion

~~122.~~ Environmental monitoring and resources exploration have been rising as the targets inspiring science and technology to research and develop new ideas, new architecture and new products particularly in aerospace. Among unmanned aerospace products, unmanned airship is very useful and proper in resources exploration and environmental monitoring in which we have achieved server practical results. It is also applicable for a range of potential field. It is a good supply for the demands of science and technology development in developing countries. This paper has proposed a dedicated architecture of our unmanned airship in the face of hardware system, software system and automatic control perspectives. Practical results were presented. Potential applications were also mentioned. This type of unmanned airship has been employed in resources exploration and environmental monitoring in Korea and Peru.

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Acknowledgement

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[1].

[2]. References

~~[2].~~[3]. ~~Ref NO??~~ Gene F. Franklin, J. David Powell and Naeini, “*Feedback Control of Dynamic Systems*”, 6th edition, Pearson Express, 2010

~~[3].~~[4]. Enric Pastor, Juan Lopez and Pablo Royo, “*A hardware/software architecture for UAV payload and mission control*”, Department of Computer Architecture, Technical University of Catalonia, Castelldefels (Barcelona), Spain.

~~[4].~~[5]. Gabriel A. Khoury and J. David Gillett, “ *Airship Technology*”, Cambrige Aerospace Series 10, 1999

~~[5].~~[6]. Michael V.Cook, “*Flight Dynamic Principles*”, edition, Elsevier Aerospace Engineering Series, 2007

~~[6].~~[7]. Pratt, R., “*Flight Control Systems: Practical Design and Implementation*”, Institution of Electrical Engineers (IEEE), 2000

~~[7]. Sung Su Kim, Tae In Oh, Kee Young Choi, Choon Bae~~ *Control System Focused on Reliability*", Journal of the KSAS, Vol. 33, No. 11, pp.33-40, 2005