Development of the Fuzzy Control for a GPS-located Airship

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Abstract

The purpose of the work is to develop the fuzzy control for the experimental GPS-located airship, which has the overall length of 5.8m and the maximum diameter is 2.2m. The basic technology including the hardware and the program to control the airship navigating along the shortest flight path to the target point is developed. Fuzzy control is used because the kinematics and dynamics features of an airship are non-linear and it is difficult to describe the motion equations. At last, to compare the efficiency, PD control is also applied. The result of comparison shows the validity of the fuzzy control.

Keywords : Autonomous airship, GPS, Side thruster, Fuzzy control

1. Introduction

For many situations, autonomous green flight systems are needed and important. They have been developed for uses such as mine detecting, crop dusting and military surveillance. Aerosonde [1], which is developed by Aerosonde Robotic Aircraft Pty Ltd., PREDETOR [2] by Inc. of General Atomics Aeronautical Systems, and RQ-4A Global Hawk [3] by Northrop Grumman Corporation are examples of these kinds of flight systems. Also the development of helicopter system was reported by Sugeno et al [4, 5] and an airship by Ouchi et al [6]. Suzuki et al have studied the control of the airship by reinforcement learning [7, 8].

In this study, the experimental airship is proposed, which can remain stationary in the sky and since it uses helium gas, it has low fuel consumption. In the paper, the basic technology including the hardware and the control method by which the airship navigates along the shortest path to the target point is discussed.

2. Structure of the system

Figure 1 shows the structure of the airship. The balloon is elliptical and has an overall length of 5.8m, a maximum diameter of 2.2m and a volume of 17.5m^3. Helium gas is used for buoyancy. The gondola at the bottom contains a notebook computer, controllers, motors, batteries, a geomagnetic sensor and ballast. For navigation, GPS (Global Positioning System) is mounted and an antenna for receiving GPS signals is fixed to the head of the balloon.

The power sources consist of a side thruster and two main fan ducts. The side thruster is used to rotate the airship around the vertical axis (yawing rotation shown in Figure 2). Two main fan ducts are used to control the airship going up, down, forward and backward.

In Figure 2, the *ox* axis is coincident with the axis of symmetry of the envelope and the *oxz* plane

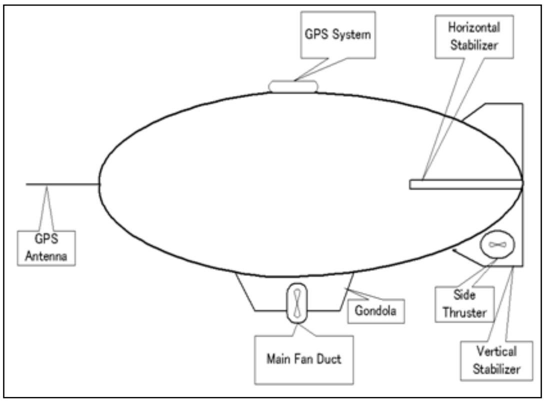

Figure 1 Structure of airship

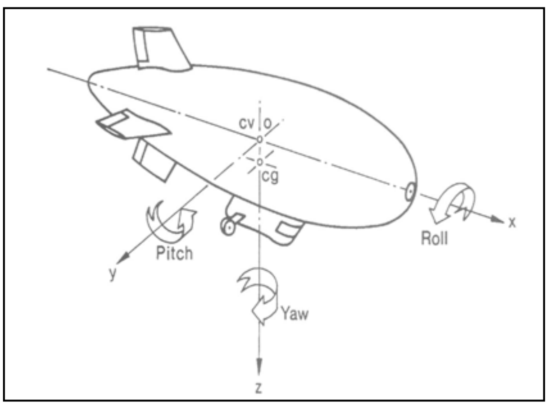

Figure 2 kinematics of airship

coincides with the longitudinal plane of symmetry of the airship. Since the volume of the gondola is negligible compared with that of the envelope, it is reasonable to assume that the *cv* (center of volume) lies on the axis of symmetry of the envelope.

The airship is able to move in translation and rotation in three dimensional spaces. Rotation around the *x* axis is called rolling, around the *y* axis is pitching and around the *z* axis is yawing. In this study the rotation of the airship is mainly yawing.

3. Control method

3.1 General algorithm

The flow chart of the automatic control algorithm is shown in Figure 3. When it starts, the airship flies up first. Next, the notebook computer receives data from each sensor. Subsequently, the position of the airship compares with the target point. When it reaches the target, the program terminates and the airship hovers. Otherwise the computer calculates the direction and distance to the target point shown in Figure 4. Values of control parameters are outputted to each motor. Eventually by repeating these processes, the airship arrives to the target point.

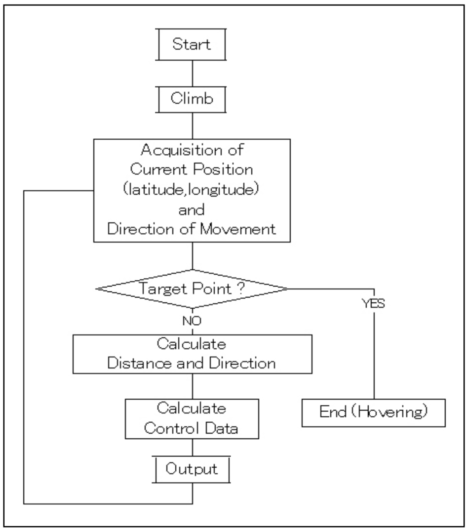

Figure 3　Flow chart

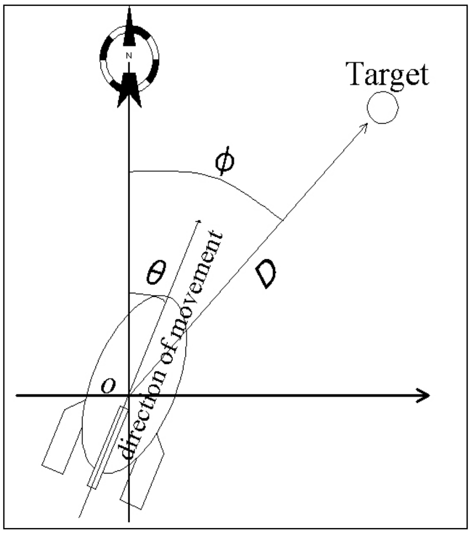

Figure 4　Coordinate of the airship to target

3.2 Control of side thruster

3.2.1 PD control

The side thruster is first controlled by PD adjustment as comparison. The thrust S_t is determined by the angular difference $\theta_d = \phi - \theta$ shown in Figure 4, the angular velocity ω (= dθ_d/dt) and the angular acceleration α (= d$^2\theta_d$/dt^2). Thus the thrust of the side thruster is expressed as follows:

$$S_t = K_\theta(0-\theta_d) + K_\omega(0-\omega) + K_\alpha(0-\alpha) \quad (1)$$

where K_θ, K_ω and K_α are constants and the target point is set to (0, 0, 0). However, it is difficult to determine these parameters because the airship is slow to respond and the characteristic of the airship is non-linear. Therefore, these constants are adjusted and determined by repeating the experiment.

3.2.2 Fuzzy control

As the other control method for the side thruster, fuzzy control is applied. Figure 5 shows the membership functions being used [9]. Inputs are the angular difference θ_d and the angular velocity ω. The membership functions have triangular forms and seven vertices. Each set is labeled NL, NM, NS, ZR, PS, PM and PL, meaning negative large, negative medium, negative small, zero, positive small, positive medium and positive large for each symbol.

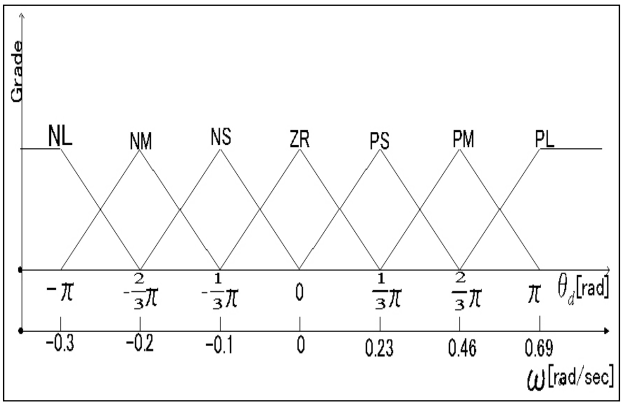

Figure 5 Membership functions

The fuzzy rules are as follows

If θ_d is A_{11} and ω is A_{12}, then S_t is B_1
If θ_d is A_{21} and ω is A_{22}, then S_t is B_2

Where A_{ij} and B_i are labels of each fuzzy set. The fuzzy output set B_i is discrete. These rules are expressed as the rule table shown in Table 1.

Table 1 Rule table for S_t

ω \ θ_d	NL	NM	NS	ZR	PS	PM	PL
NL	0	0.5	1	1	1	1	1
NM	0	0.4	0.7	0.3	1	1	1
NS	-0.7	0.3	0.5	0.1	0.3	1	1
ZR	-1	-0.5	-0.3	0	0.1	0.4	1
PS	-1	-1	-0.6	-0.4	-0.6	-0.4	0.6
PM	-1	-1	-1	-0.5	-0.8	-0.5	0
PL	-1	-1	-1	-1	-1	-0.6	0

4. Experiment

4.1 Procedure of experiment

The purpose of the experiment is to confirm that the airship navigates to the target point and to compare the two control methods for controlling the side thruster. Since the power of the motors is not very large, it is desirable that the experiment is conducted indoors, where there is little effect to disturb the flight. The space for experiment needs an area of over $1000m^2$ and a height over 20m due to the size of the airship. And since GPS signals cannot be received in a reinforced concrete building, the experiment is done in wooden building Izumo dome.

4.2 Result and Discussion

The result is shown in Figure 6. It gives two trajectories of the flight path, plotting longitude along the ordinate and latitude along the abscissa. By PD control, the airship flew changing the direction right and left before arriving at the target point. The main cause is that gains of K_θ, K_ω, K_α in equation (1) were not able to be adjusted properly. The adjustment is very difficult without analyzing the dynamic characteristics of the airship. By fuzzy control, the airship could autonomously navigate by the almost shortest flight path. The flight time is 1 minute and 27 seconds by PD control, and 20 seconds by fuzzy control.

The results of this experiment show that the fuzzy control method is more effective than the PD control method from viewpoint of tuning parameters, and the PD control method is not suitable for the autonomous airship system in the present situation.

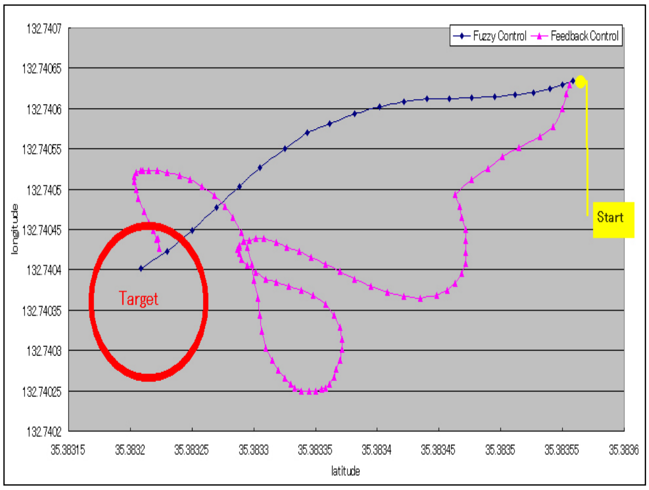

Figure 6　Results of flight controlled by Fuzzy and PD

5. Conclusions

In this paper, we proposed the control system and the algorithm for the airship to navigate autonomously to the target point. To control the side thruster, the PD and fuzzy control are applied as comparison. As the result, it is clear that the fuzzy control is better for the airship to finish the task of flying to the target point.

Further work of image processing and recognition by the CCD camera and the technology of the telecommunication are being considered. Telecommunication needs to communicate mutually the data between the computer mounted on the airship and the computer at the base station. The monitoring program using wireless LAN is developed in the project. It enables us to monitor the condition of the airship from a remote location. In the near future, we will develop integrated monitoring and operating software.

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