Fundamental research on the fuzzy control to the autonomous airship

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Abstract: The fuzzy control to the experimental autonomous airship is introduced in this paper. The fundamental development and research on the hardware and the program to control the airship navigating along the shortest flight path to the target point is executed. The fuzzy control is used because the airship system is nonlinear and it is difficult to describe the accurate motion equations of the system. At last, to compare the efficiency, the traditional PD control is also applied. The result of comparison shows the validity of the fuzzy control.

Keywords: autonomous airship, fuzzy control, side thruster

1 INTRODUCTION

Manned helicopters are used for aerial photography to obtain the geographical information. However, it results to the atmosphere pollution by the exhaust fumes. Also it will be very dangerous to navigate the region that is bearing the disaster or war.

To solve these problems, the unmanned autonomous green flying system is needed. Unmanned helicopter and airship have been developed for uses in the mine detecting, crop dusting and military surveillance. Aerosonde [1], Predetor [2], RQ-4A Global Hawk [3] and the unmanned helicopter developed by Nakamura et al. [4] are examples of these kinds of flying systems. Also Suzuki et al. [5] presented the research result of the control for the airship by reinforcement learning and adaptive control.

However, some of above systems have a little intelligent feature, and some of them have a few references and literature about the control unit because of the technology patents. Thus the detailed information cannot be gotten.

In this paper, the airship in our lab is introduced, which can remain stationary in the air and has low fuel consumption due to the usage of helium gas for buoyancy. Also 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

To control the whole system, the mechanical control of the airship, determination of flight path to the target point and the flight technology along the flight path, real-time image recognition, and the telecommunication technology, is required.

2.1 Hardware

Fig. 1 shows the airship system. The balloon is elliptical with an overall length of 5.8 meters, its maximum diameter is 2.2 meters and the volume is 17.5m^3. Helium gas is used for buoyancy. The gondola under the balloon contains a microcomputer, a CCD camera, motors, batteries, a geomagnetic and a GPS sensor, a notebook computer and ballast, shown in Table 1 [6]. For navigation, the antenna for receiving GPS signals is fixed on the head of the balloon.

Table1 Specification of Equipment

	Equipment	Company
Notebook computer	Libretto L1/060TNCM	TOSHIBA
Micro computer	H8/3048F	HITACHI
Micro computer board	AKI-H8	AKIZUKIDENSHI
GPS receiver	GM-38	SANAV
DGPS receiver	NDIDEV003	Nippon Denso Industry
Earth magnetism sensor	3D motion sensor	NEC tokin

The notebook computer mounted on the system receives the latitude and longitude values of the airship from the GPS sensor, and obtains the direction for the airship to fly to by the geomagnetic sensor. The values of control variables are calculated and transmitted to the microcomputer. And then the microcomputer converts the values into the motor drive pulses and outputs them to each motor.

The power for the motion consists of a side thruster and two main fan ducts. The side thruster is used to rotate the airship around the vertical axis (yawing rotation). Two main fan ducts are used to control the airship flying up or down, and forward or backward.

Since the volume of the gondola can be negligible if it is compared with that of the envelope, it is reasonable to assume that the center of the volume lies on the axis of symmetry of the envelope. The airship is able to move in translation and rotate in three-dimensional spaces (rolling, pitching and yawing). In this paper the yawing rotation of the airship is mainly tested.

2.2 Control algorithm

The flow chart of the control algorithm is shown in Fig. 2. The airship goes up first. Next, the notebook computer that mounted in the gondola 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 notebook computer calculates the direction and distance to the target point shown in Fig. 3. Later the control is determined and outputted to each motor. Eventually by repeating these processes, the airship arrives at the target point.

2.3 Control of the side thruster

2.3.1 PD control

The side thruster is first controlled by the PD control as comparison. As shown in Fig. 3, the thrust S_t is determined by the angular difference θ_d ($=\varphi - \theta$), the angular velocity ω ($=d\theta_d/dt$) and the angular acceleration α ($=d^2\theta_d/dt^2$). Thus the thrust of the side thruster is expressed by

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

where K_θ, K_ω and K_α are constants and the target is set to (0, 0, 0). However, it is difficult to determine these constants 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.

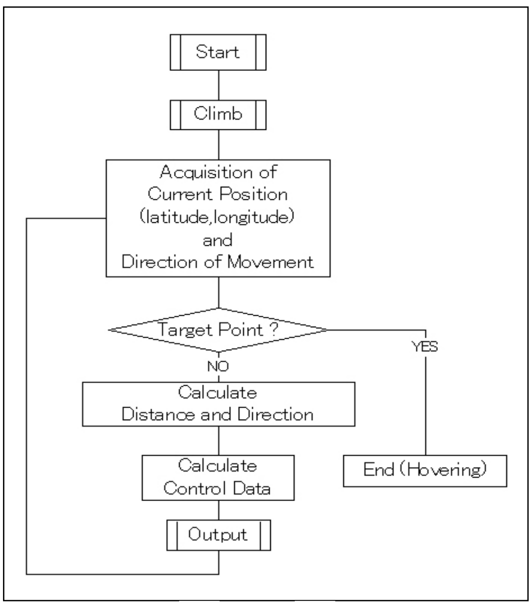

Fig. 2. Flow chart of the control algorithm

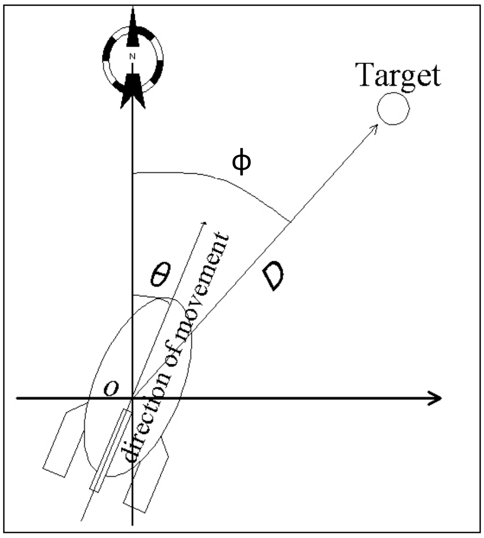

Fig. 3. Coordinate of the airship to target

2.3.2 Fuzzy control

Fig. 4 shows the fuzzy membership functions being used. Inputs are the angular difference θ_d and the angular velocity ω, output is S_t. The membership functions have triangular forms and seven vertices. Each set is labeled NL, NM, NS, ZR, PS, PM and PL, meaning negative or positive large, medium, small, and zero for each symbol. Fuzzy rules are

$$\text{If } \theta_d \text{ is } A_{11} \text{ and } \omega \text{ is } A_{12} \text{ then } S_t \text{ is } B_1$$
$$\text{If } \theta_d \text{ is } A_{21} \text{ and } \omega \text{ is } A_{22} \text{ then } S_t \text{ is } B_2 \quad (2)$$

where A_{ij} and B_i are labels of each fuzzy set, and the fuzzy output set B_i is discrete, shown in Table 2.

Table 2. Rule Table 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

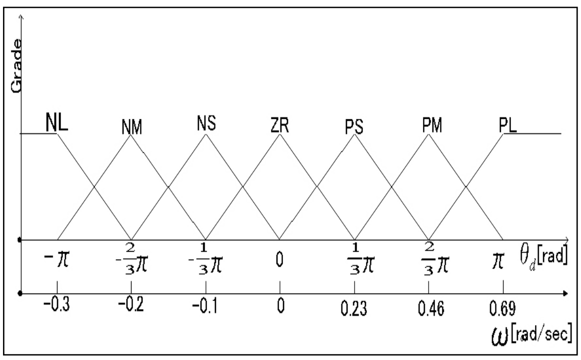

Fig. 4. Membership functions for inputs

2.4 Data Flow

Fig. 5 shows the block diagram of the data flow. Latitude and longitude values of the target point are set initially. In Fig. 3, D and φ are calculated as the difference between the positioning data of the target point and those obtained from the GPS. The angular difference θ_d ($=\varphi - \theta$) is the input variable to the side thruster controller, where the angle θ is the forward direction of the airship. D and θ_d are also inputs to the main fan duct controller [7].

3 EXPERIMENT

3.1 The task

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. It is desirable that the experiment is done indoors, where there is little influence to disturb the flight.

3.2 Result and analysis

The result is shown in Fig. 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 reason is that the gains K_θ, K_ω, K_α in equation (1) are not set properly. The adjustment is very difficult without getting the perfect dynamic characteristics of the airship. By fuzzy control, the airship could autonomously navigate by almost the shortest flight path. The flight time is 1 minute and 27 second by PD control, and 20 second by the fuzzy control.

Fig. 7 shows another experiment controlled by the fuzzy algorithm. The airship starts from the "Start" point, and returns from the position "Target" to the "Goal" [8].

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

3.3 Landing stage

When the flying action is accomplished, it is time for the airship to land (or hover). The CCD camera on the airship searches the letter P or H (means parking point) on the land. Operation, such as image processing and segmentation, is done to find the letter P. And then automatically adjust the airship to land on the mark.

The question is how to make the airship recognize the mark rapidly. In practical application, the camera on the airship seldom sees the perfectly vertical P, always is italic or has random angle. Thus the recognition system needs to store a large number of templates for the letter P. In fact, moment invariance [9] can solve this problem. We can mapping the different angles to the few templates by invariant moment shown in Fig. 8.

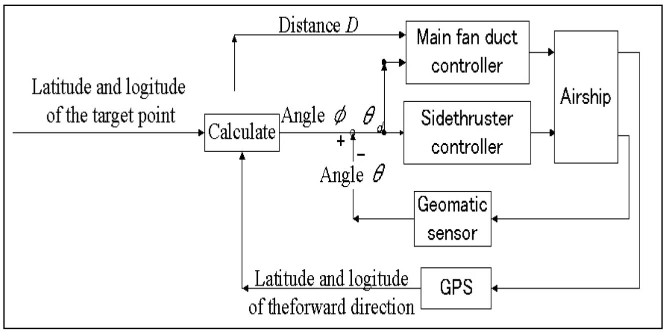

Fig. 5. Block diagram of data flow

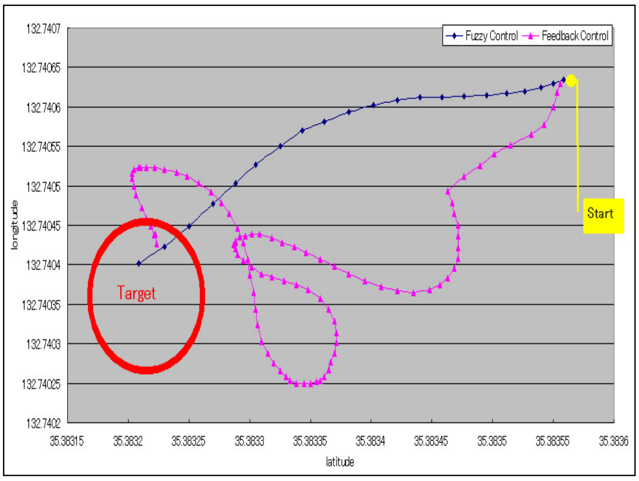

Fig. 6. Results of flight controlled by Fuzzy and PD

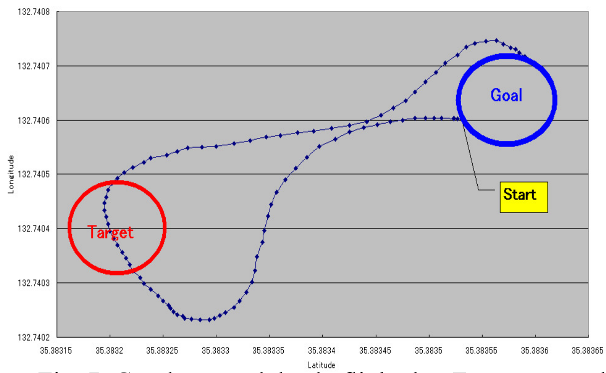

Fig. 7. Go there and back flight by Fuzzy control

Fig. 8. Template of the letter P

4 CONCLUSION

In this paper, the simplified control system and the algorithm for the airship to navigate autonomously to the target point are proposed. To control the side thruster, the PD and the fuzzy control are applied respectively as comparison. As the result, it is clear that the fuzzy algorithm enables better control for the airship to reach the preset target point.

Of cause if the kinematics description of the airship's side thruster control and the PD parameters are set more accurate, the result for the PD control should be better than the proposed result in this paper. The contribution of this paper is to express that the fuzzy control is more suitable for the intelligent control system.

Further work of pattern recognition to a special object on the land by the single or stereo CCD cameras and the technology of telecommunication are being considered. Telecommunication technology is used to communicate mutually the data between the notebook computer mounted on the airship and the computer at the base station to establish the servo-client system. And the monitoring program by using wireless LAN should also be developed, which enables us to monitor the condition of the airship remotely.

ACKNOWLEDGMENT

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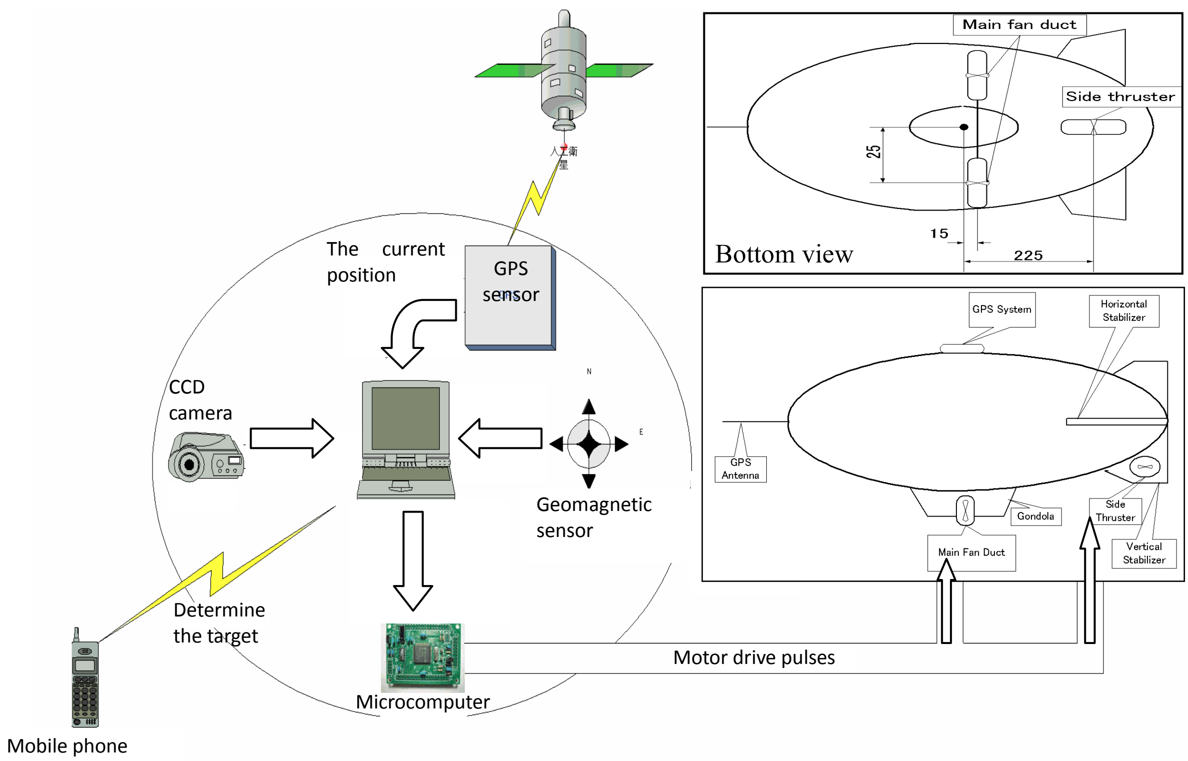

Fig. 1. The structure of the whole system