A BLIMP-ROBOT GUIDANCE
BASED ON A PID APPROACH WITH FUZZY CONTROL

Plamena Andreeva Valentine Penev Ognyan Manolov
e-mail: [plamena, valentrin.penev, o.b.manolov]@icsr.bas.bg
Bulgarian Academy of Sciences, Institute of Control and Systems Research,
Laboratory of Mobile Robotics – LAMOR, Sofia 1113, P.O. Box 79, Bulgaria

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ABSTRACT

The design and investigations of autonomous blimp-robot delivery system is considered. Advanced sensors for a flight critical information of environment conditions and last-minute updates feed the onboard-computerized guidance system to respond and control a set of actuators for maneuvering the blimp-robot. A fuzzy control to guide the system to the landing point is used. To demonstrate the dynamical charchteristics of the blimp-robot a simulaton program is used.

I. INTRODUCTION

The sky industry soon recognized the potential and the paragliding was born. With the aid of modern materials paragliding quickly evolved into highly portable inexpensive and relatively safe way for people to explore the air. From the ground, the transport aircraft at 10000 m. is a mere speck in the sky, and the payload kicked out the back is invisible in the early morning darkness. The transport airplane is well on its way home by the time the delivery drops into target zone; the 20-minute descent is autonomous, silent, passive and purposeful. The ram air canopy swings wide of a known air defence battery and several towns and villages. A special operation team collects urgently needed supplies and then disappears into the night. The basic idea of fuzzy control approach is to incorporate fuzzy IF-THEN rules into the control design. Fuzzy control combines two resources: input-output data and the experts' experience expressed by rules. The problem of incorporating expert knowledge is wide studied and found applications in variety of control, signal processing and information systems, [4, 6]. The advantage of the fuzzy system approach compared with other non-linear regression methods is that fuzzy systems are universal approximators and have also clear physical interpretation for their structures and parameters so that the results can be interpreted in terms of fuzzy IF-THEN rules. The basic problem in the fuzzy control application is the analysis of the transmitted uncertainty from the premises to the conclusion. Cluster analysis of the input domain based on [1] helps to a reasonable extent in the management of uncertainty in such situations. Our fuzzy approach combines the power of fitting complex data from the attached information system and the possibility of structuring the knowledge by linguistic rules. More important, the analysis eventually leads to a new representation of the input data. By the design of such an intelligent information system we seek to make the control process of flying object easy, at low cost and possible to be explained by request. The paper presents requirements for designing autonomous systems that include humans and autonomous agents who interact to achieve complex goals. Such systems are known as human-centered autonomous agents. Our fuzzy approach combines the power of fitting complex data from the attached information system and the possibility of structuring the knowledge by linguistic rules. More important, the analysis eventually leads to a new representation of the input data. Our goal is to create autonomous systems that minimize the necessity for human interaction, but maximize the capability for humans to interact at whatever level of control is most appropriate.

II. A BLIMP-ROBOT DYNAMICAL MODEL

The flight guidance system weights approximately 100 pounds and includes a GPS receiver, air speed indicator, compass, barometric altimeter, radio modem, laser altimeter, rate gyros, servos and batteries. These sensors provide information on wind speed and direction, as well as vehicle airspeed, oscillation and position. An onboard computer digests this information to navigate vehicle. The blimp-robot and its equipment are shown in Fig. 1.

Fig. 1. Blimp-robot and the on-board equipment

The fuzzy control is used to guide the system to the landing point. An associated information system is proposed to store the results from possible training made by an expert and distributed via network.

The blimp-robot dynamic model is synthesized where features as a dynamic breaking, collapse and chain between pitch and yaw are presented. The simulation program is used to demonstrate the dynamical characteristics of the blimp-robot. A clustering method was developed to determine the number of rules during the training process. The proposed approach can acquire a satisfied performance by learning in fuzzy environment. The optimization of rule base and membership functions is performed at the same time. A classification is usually thought of as a partitioning of a set of data into subsets in which the members are "more similar" to each other than to non-members. In our approach, class membership is expressed fuzzy rather than as logical assignment. This research is related to the search of the suitable rule sets of the fuzzy classify system.

III. THE AUTOMATIC CONTROLLED SYSTEM

The modern fuzzy control is used to design an automatic controlled system for the blimp-robot. The control system endows the blimp-robot with capability to land on the defined point in its range. The model assumed the blimp-robot as a point-mass that gives an account of its no rigid structure. The altitude, airspeed, vertical speed and angular position are measured. The control of the blimp-robot is done by IF-THEN rules. Fuzzy control combines two resources: input-output data and the experts' experience expressed by rules. The a priori information is given in the initial state of input data. For the partitioning of input data we assume that the fuzzy sets of φ and ν_n have symmetric triangular membership functions.

This model presents an intermediate class blimp-robot realistically. The blimp-robot has a somewhat different azimuth control, which are bank and attack angles directed. The blimp-robot primary flight-control surfaces consist of horizontal stabilizers capable of symmetric or differential movement. The model includes two identical actuators for stabilizer surfaces. These actuators are rated limited at 40 deg/s. and have first-order responses modeled by G(p) = 10/(p+10). The command inputs to the stabilizers are symmetric and differential, which are separated into inputs to each of surface actuators models. Two CCD cameras mounted on the blimp-robot are used to determine down and cross ranges to the landing point. Fuzzy controller rules are synthesized on the base of available knowledge about the system. Blimp-robot pitch and yaw control loops are shown. The fuzzy controlled blimp-robot response with navigation guidance law for defined point landing is evaluated and discussed. The simulator program under Windows 3.1 is designed. The arm and fuzzy controls are available. The results show that blimp-robot model and fuzzy controlled blimp-robot are appropriate for a variety of control and guidance applications. The findings may be used to design a real blimp-robot controller, which can be employed for surface surveillance by the Army or other user.

Nomenclature. The following notations are used:

C_D, C_{D_0} - drag coefficient and zero-lift drag coefficient
C_L, $C_{L\alpha}$ - lift coefficient and its partial derivative of α
D - drag force
g - acceleration of gravity
h - altitude
L - lift force
m - mass of blimp-robot
s_t - blimp-robot reference area
ν - velocity of blimp-robot
α, α_c - angle of attack and its command
α_0 - zero lift angle
γ, ψ - blimp-robot flight-path and azimuth angle
ρ - air density
σ - line-of-sight angle
ϕ - blimp-robot bank angle
w_x, w_y, w_h - wind velocities along the x- , y- , h-axis

IV. THE BLIMP-ROBOT MODEL

The model of aerial flying vehicle [2, 3, 5] suppose the blimp-robot to be a point-mass that gives an account of its non rigid structure. This model presents an intermediate class blimp-robot realistically. The blimp-robot has a somewhat different azimuth control, which are bank and attack angles directed. The numerical blimp-robot model has about 90% similarity with the real blimp-robot dynamics. The collapse, dynamic breaking, chain between pitch and yaw channels are part of main characteristics. Some of normal values are listed as follows:

$m_t = 85$ kg; $v_{t_0} = 6$m/s; $s_t = 27.0\text{m}^2$;
$h_{t_0} = 300$m; $T_1 = 0.10$s; $T_N = 0.6$s;
$k_1 = 4.0$ 1/s; $k_{S_l} = 200.0$; $k_2 = 0.1$s

$$\dot{v}_t = \frac{-D}{m_t} - g \cdot \sin\gamma_t - w_x \cdot \cos\gamma_t - w_h \cdot \sin\gamma_t; \quad (1)$$

$$\dot{\gamma}_t = \frac{L}{m_t v_t}\cos\phi - \frac{g}{v_t}\cos\gamma_t - \frac{(w_x \cdot \sin\gamma_t - w_h \cdot \cos\gamma_t)}{v_t}; \quad (2)$$

$$\dot{\psi}_t = \frac{L}{m_t v_t \cos\gamma_t} \cdot \sin\phi; \quad (3)$$

$$\dot{h}_t = v_t \sin\gamma_t; \quad (4)$$

$$\dot{x}_t = v_t \cos\gamma_t \cos\psi_t; \quad (5)$$

$$\dot{y}_t = v_t \cos\gamma_t \sin\psi_t; \quad (6)$$

where $L = \frac{1}{2}\rho \cdot v_t^2 \cdot s_t \cdot C_L \cdot f^L(v,\gamma,\phi)$;

$$C_L = C_{L\alpha}(\alpha - \alpha_0);$$

$$D = \frac{1}{2}\rho \cdot v_t^2 \cdot s_t \cdot C_D \cdot f^D(v,\gamma,\phi);$$

The blimp-robot primary flight-control surfaces consist of horizontal stabilizers capable of symmetric or differential movement. The individual surface position limits and rate limits are detailed as follow:

- symmetric stabilizer for attack angle, left and right - 0-45 deg, 40 deg/s;
- differential stabilizer for bank angle, left and right - 0-45 deg, 40 deg/s

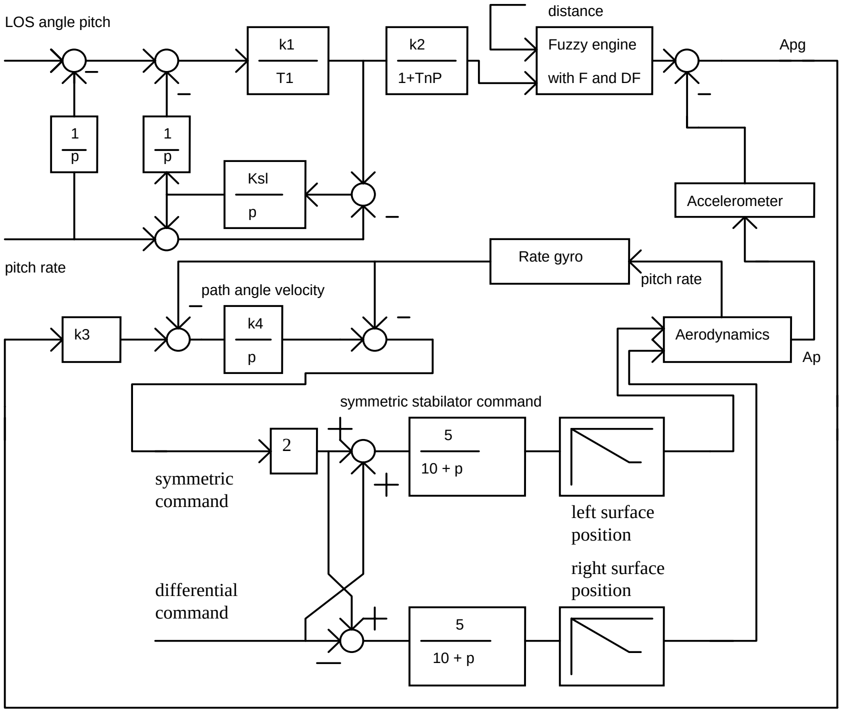

Fig. 2 Pitch control loop

The model includes two identical actuators for stabilizer surfaces. These actuators are rated limited at 20 deg/s. The actuators have first-order response modeled by G(p) = 10/(p+10). The command inputs to the stabilizers are symmetric and differential, which are separated into inputs to each of surface actuator's models. The blimp-robot is controlled by angle of attack and bank angle or in the respect of goal point position. Blimp-robot pitch control loop and the part of yaw loop are shown in Fig.1.The yaw control loop is similar and has the following differences. Of course the symmetric command belongs to the pitch loop and differential command belongs to the yaw loop. Symmetric stabilizer command is changed with differential stabilizer command.

V. THE FUZZY CONTROL

The three input variables are used in the following way: For the input variables φ^p and φ^a six fuzzy allegiances are considered as follows - NB, NM, NS, PS, PM, PB and for input variable φ^d five fuzzy allegiances are considered ZO, PS, PM, PB, PVB. For the control bank and attack angles six fuzzy allegiances NB, NM, NS PS, PM, PB are considered. Input variable φ^d is introduced to minimize the static error and to make response faster. Detailed description of the inputs and outputs is viewed in Table 1.

Our fuzzy approach combines the power of fitting complex data from information system and the possibility of structuring the knowledge by linguistic rules. More important, the analysis eventually leads to a new representation of the input data.

Table 1. Description of input and output fuzzy allegiances

φ^p - LOS pitch vel.	$k\times\varphi^p\in(-\pi;\pi)$	nb	nm	ns	ps	pm	pb
φ^a - LOS azimuth velocity	$k\times\varphi^a\in(-\pi;\pi)$	-π	-0.5π	-0.15π	0.15π	0.5π	π
φ^ddist. between para	up to 2000m	zo	ps	pm	pb	pvb	
Glider and land-point		0	π/2	π	3π/2	2π	
Fuzzy bank	$\in(-\pi;\pi)$	nb	nm	ns	ps	pm	pb
angle		-a	-2a/3	-a/3	a/3	2a/3	a
fuzzy attack angle	$\in(-0;\pi)$	nb	nm	ns			
		-b	-2b/3	-b/3			

Classification of a priori knowledge and identification of new data are central in the fuzzy control process. Fuzzy control for blimp-robot is characterised by model uncertainty and inequality model constraints. By unsupervised learning, the performance error on inferring procedure has no effect on the operation of the clustering algorithm. In unsupervised mode, the primary measure that affects the goodness of a cluster is the performance error. How to acquire the control rules and how to determine the parameters of membership functions are the bottleneck problems in the fuzzy control design process. Using the sample learning based neural network during the past years has achieved a greet success. However, when the heuristic knowledge of the experts and sensor measured training samples are not available, the neural network based learning is hard to be used. In order to acquire the high performance fuzzy controller, the structure and parameters of fuzzy system should be optimized at the same time. There exist 3 methods for fuzzy controller optimization based on the structure (rule base) and parameters (membership functions):

a) the linguistic control rules are definite, the objective is to optimize the parameters of the membership functions;
b) the fuzzy sets are definite while using algorithm to find the optimal rule base;
c) the optimization of rule base and membership function is performed at the same time.

The off- line design for genetic-based fuzzy systems are usually implemented due to the computational complexity. Recently some research is conducted to complete the on-line design of fuzzy systems by using some genetic based machine learning schemes, [5]. These learning approaches are similar to the search for fuzzy rules of fuzzy classifier systems. In this paper we consider mainly the fuzzy system optimization for off-line design. The overall design flow chart is illustrated as Fig. 2.

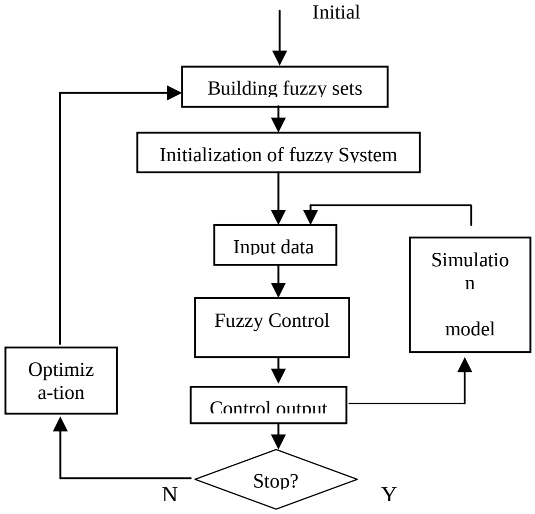

Fig.2. Design flow chart of fuzzy control system with optimization

Initial fuzzy controller rules were synthesized on the base of available knowledge about the system. The fuzzy engines have optimized structurally and parametrically [2] in the following procedure:

- structural optimization in the full range of possible combination between rules;
- parametric optimization on the base of maximal grades of fuzzy allegiances;
- repeating the above two steps until appropriate trajectory errors.

Each of the pitch and yaw control loops have a fuzzy engine with two input variables φ^p/φ^d and φ^a/φ^d and one output attack angle and bank angle. The linear and sinusoidal shapes of membership functions were tested. The better trajectory errors were obtained with linear shape of membership functions. The most important feature of the fuzzy engines is the separation the pitch and the yaw channels. The interconnection between pitch and a yaw channel has very simple linguistic expression:

- IF bank angle is changed THEN path angle is changed and azimuth angle is changed;

- IF attack angle is changed THEN path angle is changed and azimuth angle is changed.

Table 2. Fuzzy control rules for pitch loop

φ^p / φ^d	ZO	PS	PM	PB	PVB
PB	nb	nb	nb	nb	nb
PM	nb	nm	ns	ns	nm
PS	nm	ns	ns	nm	ns
NS	ns	nm	ns	nm	ns
NM	nm	nb	nm	nb	nm
NB	nb	nb	nb	nb	nb

Table 3. Fuzzy control rules for yaw loop

φ^a / φ^d	ZO	PS	PM	PB	PVB
PB	ns	ns	nm	nb	nb
PM	ns	nm	nb	ns	nm
PS	ns	ns	ns	ns	ns
NS	ps	ps	ps	ps	ps
NM	pm	pb	pm	pb	pm
NB	pb	pb	pb	pb	pb

In the respect of these two rules the appropriate corrections are used. In our case this is third input signal - φ^d - distance between blimp-robot and land-point.

VI. CONCLUSION

The general features of a fuzzy controlled blimp-robot were studied and tested by simulation and the results were shown to blimp-robot pilots. The fuzzy controlled blimp-robot response with navigation guidance law for defined point landing is evaluated and positively discussed. The simulation results show that blimp-robot model and fuzzy controlled blimp-robot are appropriate for a variety of control and guidance applications. Similarly, any constraint on the lowest altitudes can make critical collapse. Now, the fuzzy controller can not make decision in this situation. This paper provides an opportunity for enthusiasts to apply system design methodology to a realistic flight vehicle. The results from this investigation may be used to design a real blimp-robot controller, which can by employ for surface surveillance by the Army or other user.

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