Trajectory Simulation and Fuzzy Control for a Parafoil Payload Delivery System

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ABSTRACT

This report describes the investigation of simulation and control of an autonomous Parafoil Payload Delivery System based on the fuzzy concept. Modern airdrop systems face the problem of proper delivery of a payload to a desired location well away from the release point. The guidance and control algorithm must be able to give precision landing while being robust and easy to model and work with. Fuzzy logic and control is helpful in this case. Fuzzy logic will also consider the uncertainties in the system and hence ensures reliability.

Initially, a conceptual design of the Parafoil is made and an appropriate wind model is also generated. Then the mathematical model of the Parafoil equations of motions will be formed and they will be solved to determine the attitude and location. With the help of Artificial Neuro Fuzzy Inference System, the model will be trained with the available data obtained through the mathematical model. Result of the training is that, when a new desired trajectory is fed into the system, it will perform all the necessary actions to follow that trajectory based on the learning.

KEY WORDS: Parafoil Payload, Fuzzy.

1. INTRODUCTION

Parafoil, Payload Delivery System: A ram-air parafoil is a modern type parachute whose speed and direction can be controlled by the pilot or a control module. A ram air parafoil is self – inflated through an opening in its leading edge that gives the necessary airfoil shape. Parafoil based aircraft are capable of delivering a wide range of payloads to desired locations and can also be used for other miscellaneous purposes. These parafoils can be released from a particular altitude and distance from the target and from there it will navigate to the desired location. It can also be launched from the ground if it is assisted with a propulsion system. An inexpensive guidance and control module is used along with the payload for autonomous control.

The main advantage of Parafoils is that they offer easy navigation because of the wing like shape and control surfaces, which is not possible in the case of round parachutes.

Working of the Parafoil: The canopy of the parafoil behaves as a wing after it is inflated as air rams in through the leading edge opening of the parafoil. Handles called toggles are connected to the rear edge of the left and the right sides of the parafoil through two sets of lines. Pulling the left toggle lowers the rear edge of the left side of the canopy. This makes the left side of the parachute to slow down and hence the Parafoil turns to the left. Similarly, right turn can be made with the help of the right toggle. On pulling both the toggles together, the whole canopy slows down and behaves like a brake. It helps in flaring that is rapid deceleration to come to a stop during landing. A good level of control enables precise landings possible.

Conceptual Design: A conceptual design of the Parafoil is carried out to determine, the basic system performance and other aerodynamic parameters as well as the dynamic terms. To be concise, the calculations are skipped and the parameters are shown in the tables below.

Table.1. Parafoil Characteristics

Parafoil Payload System Characteristics	
Total Mass	110 kg
Wing Loading	5 kg/m^2
Canopy Span Area	22 m^2
Aspect Ratio	3
Canopy Span	8.124 m
Chord	2.708 m
Line Length	6.4992 m
Airfoil	NASA LS(1)0417
Ixx	822.8348 kg-m^2
Iyy	724.5607 kg-m^2
Izz	121.8768 kg-m^2
Ixz	5.0811 kg-m^2

Table.2. Aerodynamic Coefficients

Aerodynamic Coefficients	
$C_{L\delta}$, Single Flap	0.002 rad^{-1}
$C_{L\delta}$, Both Flaps	0.005 rad^{-1}
$C_{D\delta}$, Single Flap	0.00066 rad^{-1}
$C_{D\delta}$, Both Flaps	0.00135 rad^{-1}
$C_{m\delta}$, Single Flap	-0.00015 rad^{-1}
$C_{m\delta}$, Both Flaps	-0.00064 rad^{-1}
C_{nr}	-0.0248 rad^{-1}
$C_{n\delta}$	0.003334 rad^{-1}
$C_{l\delta}$	0.010117 rad^{-1}

Fuzzy Logic Control: Fuzzy logic is revolutionary in modern control technology. The simplicity of the control module is very promising in the development of control systems for complicated systems whose mathematical governing equations are difficult to solve or the non – linearity of the system is very high. Unlike the classical control theory, fuzzy control takes membership values between 0 to 1 i.e. instead of verifying whether true or false; it looks for the trueness of a membership. Fuzzy logic controllers are used particularly for non – linear dynamic systems

ISSN: 0974-2115
www.jchps.com
Journal of Chemical and Pharmaceutical Sciences

where there are multiple inputs and multiple outputs. Fuzzy logic algorithms contain elements of the human way of thinking and problem solving. The control systems are trained with human experience and the system decides how to control based on this learning experience. The non – linear characteristic of a fuzzy control contributes to higher robustness of the system.

Membership Function and Fuzzy Sets: A membership function of a set is a function that assigns values or membership degree to every member belonging to the set. Then that set is known as a fuzzy set. The membership function can be of the following types,

- Triangular
- Trapezoidal
- Gaussian
- Bell shaped or singleton.

Linguistic Variables: Humans are used to linguistic terms for values like near, far, very far, high, low, very low etc., In a similar manner, these linguistic variables can be used in implementing control. These are better than using numerical values that do not replicate human intelligence.

3. Parafoil and payload Model: The Parafoil and payload system is represented by a 6 – DOF system consisting of the three inertial positions of the Parafoil – payload mass center and the three Euler orientation angles. The equations of motion of the Parafoil payload system and the transformation and rotation matrices for coordinate transformation are shown below,

$$\begin{Bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{Bmatrix} = T^T \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}$$

$$\begin{Bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{Bmatrix} = \begin{bmatrix} 1 & s_\phi t_\theta & c_\phi t_\theta \\ 0 & c_\phi & -s_\phi \\ 0 & s_\phi/c_\phi & c_\phi/c_\theta \end{bmatrix} \begin{Bmatrix} p \\ q \\ r \end{Bmatrix}$$

$$\begin{Bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{Bmatrix} = \frac{1}{m_T}(F_A + F_W) - T S_\omega T^T \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}$$

$$\begin{Bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{Bmatrix} = I_T^{-1}\left(M_A - S_\omega I_T \begin{Bmatrix} p \\ q \\ r \end{Bmatrix}\right)$$

$$F_A = \frac{1}{2}\rho S V_A (C_{L0} + C_{L\alpha}\alpha + C_{L\delta a}\delta_a) \begin{Bmatrix} w \\ 0 \\ -u \end{Bmatrix}$$

$$- \frac{1}{2}\rho S V_A (C_{D0} + C_{D\alpha}\alpha^2 + C_{D\delta a}\delta_a) \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}$$

$$M_A = \frac{1}{2}\rho S V_A^2 \begin{Bmatrix} C_{l\varphi}\bar{b}\phi + \dfrac{C_{lp}\bar{b}^2 p}{2V_A} + \dfrac{C_{l\delta a}\delta_a \bar{b}}{\bar{d}} \\[2ex] C_{m0}\bar{c} + C_{m\alpha}\bar{c}\alpha + \dfrac{C_{mq}\bar{c}^2 q}{2V_A} \\[2ex] \dfrac{C_{nr}\bar{b}^2 r}{2V_A} + \dfrac{C_{n\delta a}\bar{b}\delta_a}{\bar{d}} \end{Bmatrix}$$

$$T = \begin{bmatrix} c_\theta c_\psi & c_\theta s_\psi & -s_\theta \\ s_\phi s_\theta c_\psi - c_\phi s_\psi & s_\phi s_\theta s_\psi + c_\phi c_\psi & c_\theta s_\phi \\ c_\phi s_\theta c_\psi + s_\phi s_\psi & c_\phi s_\theta s_\psi - s_\phi c_\psi & c_\phi c_\theta \end{bmatrix}$$

$$S_\omega = \begin{bmatrix} 0 & -r & q \\ r & 0 & -p \\ -q & p & 0 \end{bmatrix}$$

$$I_T = \begin{bmatrix} I_{XX} & 0 & I_{XZ} \\ 0 & I_{YY} & 0 \\ I_{XZ} & 0 & I_{ZZ} \end{bmatrix}$$

$$F_W = m_T g \begin{Bmatrix} -s_\theta \\ s_\phi c_\theta \\ c_\phi c_\theta \end{Bmatrix}$$

Wind Modeling: Parafoil is easily affected by the wind. Hence, knowledge about the wind profile is necessary to achieve proper control.

Future wind profile through the atmosphere is predicted with the help of periodic radiosonde data through the ARMA (Auto Regressive Moving Average). Here, radiosonde data for the Chennai station for the years 2012, 2013 and 2014 is used for forecasting.

Apparent Mass Effect: Apparent Mass is defined as the quantity having the dimensions of mass that is added to a body moving non-uniformly in a fluid medium in order to consider the effect of the medium on the body. For Airplanes, it is negligible because of high wing loading, but for Parafoil, the canopy loading is less than 5 kg/m^2 and hence, these terms have to be considered. The apparent mass terms are calculated with the help of empirical relations provided by Lissaman and Brown who modeled the Parafoil as a cylindrical body.

Table.3.Apparent Mass Effects

Apparent Mass Effects			
Description	Symbol	Value	Unit
Surge term	A	25.54172	Kg
Side Slip Term	B	3.9316	Kg
Plunge Term	C	34.86231	Kg
Roll Term	I_A	139.6911	kg-m^2
Pitch Term	I_B	9.009351	kg-m^2
Yaw Term	I_C	141.631	kg-m^2

Fuzzy Training and Simulation: Knowing the forward kinematics of a system, the inverse kinematics of the system can be deduced with the help of a fuzzy inference system constructed using fuzzy logic. Though it is difficult to obtain expressions for inverse kinematics of the mathematical equations of motion due to coupling effects; it is however easier to obtain the forward kinematics data through mere calculations. This data will give out the position and orientation with respect to the flap deflection angle, angle of attack, wind speed and direction, sideslip etc,. This data is used for ANFIS (Adaptive Neuro – Fuzzy Inference System) network. The learning abilities of neural networks are brought into fuzzy logic using ANFIS. It trains the membership functions with the help of input – output data.
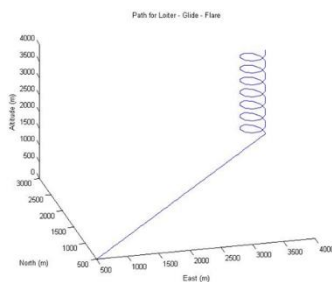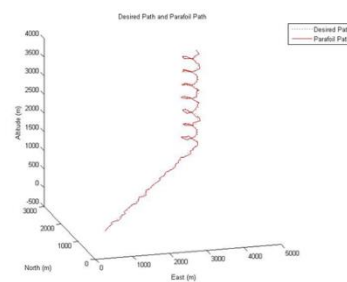

Figure.1. Desired Path   **Figure.2. Desired Path and Parafoil (Simulated) Path**
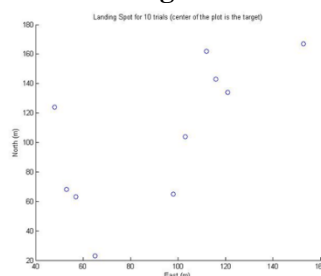

Figure.3. Landing Offset Spots for 10 trials

2. CONCLUSION

The results of the simulation indicate that fuzzy logic is suitable for the control of Parafoil – payload delivery systems. The final plot shows the landing positions for a number of trials. Most of the landing spots are well within a 100 m radius, however offsets of a few trials are very large and that has to be overcome by proper tuning.

The Parafoil system follows the desired path to an acceptable accuracy. This is because of the noise component of the wind. Precision landing was also required but there are a few limitations. In further research work, this has to be improved.

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