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Design Genetic Algorithm Optimization Education Software based Fuzzy Controller for a Tricopter Fly Path Planning

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In this paper, the feasibility of a Genetic Algorithm Optimization (GAO) education software based Fuzzy Logic Controller (GAO-FLC) for simulating the flight motion control of Unmanned Aerial Vehicles (UAVs) is designed. The generated flight trajectories integrate the optimized Scaling Factors (SF) fuzzy controller gains by using GAO algorithm. The proposed controller underlines the superior tracking performance over standard Fuzzy Logic Controller. It is highly adaptive and can counteract environmental disturbances while guaranteeing global asymptotic stability and robust waypoint tracking.

Keywords: education software, fuzzy logic controller (FLC), genetic algorithm optimization (GAO), motion flight path planning

INTRODUCTION

The UAVs are flying aerial vehicles, due to their flight capabilities, they offer the challenging tasks. The high agility and autonomy of small-scaled UAVs lead to application in different fields from civilian information search environmental monitoring, meteorological observation to rescue operations or even military surveillance. The successful accomplishment of such applications requires that the flight motion control is able to maintain the highest stability and precision for a long time. Thus, the aerial of maneuver achievements including hovering, navigation, flying path and obstacle avoidance are vital. UAVs (Cleave, 2004, Kim, 2002, Castillo,

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2007, Medagoda, 2014, Borhaug, 2005, Cruz, 2005, Yoon, 2013, Chiou, 2013, Budiyono, 2007) are multiple input multiple output (MIMO), nonlinear, under-actuated, unstable and highly coupled systems (Yoon, 2013, Chiou, 2013). Because of these characteristics, the system controller is designed to face up the challenging missions. The Tricopter is endowed with capabilities for independent sense, planning and action in coordination with other agents or environments.

Motion fly path planning of UAVs have been designed for flight route testing. Since the UAVs moving in 3D space for surveillance tasks, the popular motion is suggested (Kim, 2002, Castillo, 2007, Medagoda, 2014, Ana, 2012) the Helix flight path.

Waypoints (named also is Point of Interest "POI") are the sets of coordinates that identify a point in physical space. It is usually used to express the desired autonomous vehicle trajectory (Castillo, 2007, Borhaug, 2005, Suzuki, 2013). Waypoints nowadays are more often allied with physical artifacts created specifically for navigation activities such as radio beacons, buoys, satellites and the control points.

Fuzzy logic controllers (FLC), which is based on expert knowledge, have the advantage solution to the topics that human operators can realize. It have been applied successfully in many control system issues and even given better results than others (Fu, 2013, Chiou, 2013, Mandani, 1977). Fuzzy rule-based model is suitable when information about the physical process is vague and data availability is scarce. This paper deals with the design of the triangular membership functions and optimizes Scaling Factors (SF) as the inputs to fuzzy systematic controller. Fuzzy logic controllers have a good association with Genetic Algorithms in the Artificial Intelligent (AI) fields, including reasoning, knowledge, planning, communication, etc. There are a large number of AI software such as searching and mathematical optimization, probability and economics.

Genetic Algorithms (GAs), introduced in 1975 by Holland [9], is a heuristic search and optimization technique inspired by natural evolution. A wide range of significant complexity real-world problems has been successfully applied (Antunes, 2014, Chiou, 2009) by GAs. Each GA operates on a population of artificial *chromosomes*. These strings, which usually are binary, are in a finite alphabet. Each chromosome represents a solution to a problem and has *fitness* as a real number that measure how good of a solution to the particular problem. The best bit patterns are gradually selected during the GA course. The minimize/maximize value of the fitness function is then optimized.

Minimizing "the Integral of Time multiplied by Absolute Error" (ITAE) is commonly referred to a good performance index method (Martins, 2013), especially on the digital systems. Based on the error calculation criterion, it can be easily applied to different models such as fitness function, system performance, etc.

The education software, from theory teaching to industry applying (Mead, 2009, Lee, 2011, Huan, 2012), have designed and implemented due to bringing the vivid vision to the students. The proposed GAO software controller optimized SF of FLC by minimizing the ITAE fitness function, is suggested in this paper. The GAO-FLC can

State of the literature

- Dynamics of Motion: The triple tilting rotor UAVs, based on Newton-Euler mathematical formulation, which has three rotorcrafts speed and one tilt angle as four inputs, is presented with six Degree of Freedom (DOF).
- Waypoint tracking: The autopilot controllers tune autonomous flight waypoint tracking in preparation for advanced navigation research..
- Genetic Algorithm Optimization (GAO): The GA optimization method is chosen for the purpose of optimizing the scaling factor (SF) gains of the PD like Fuzzy controller.

Contribution of this paper to the literature

- The numerical simulations flight path planning is generated by the popular motion: Helix flying path.
- The LQR controller was used to verify the controllability and stability of the single tilt Tricopter movements.
- The proposed controller software illustrated superior and the highest accurate tracking trajectory overwhelming the standard FLC.

solve the trajectory planning and control problem in solitary step to achieve the fully autonomous operations of UAVs. This constitutes a promising one-step solution for trajectory generation and regulation for UAVs. Hence, the vehicle dynamics and environmental eventualities could be operating under various uncertainties and constraints.

TRICOPTER CONFIGURATION DESCRIPTION AND MODELING

Coordinate frame

The two right-hand coordinate frames are used to scope this project, one is the earth – fixed inertial frame and the other is Tricopter body – fixed system. In many tracking and motion planning applications, the ordinary *East, North, Up* (ENU) global system of the inertial frame is verified. The "East" direction goes along with x-axis while "North" direction is the same as y-axis and z-axis coincides to "Up". Positive x-axis points towards the front rotors (rotors 1 and 2), positive y-axis points towards right (rotor 2), and positive z-axis is directed downwards. Positive sense of the three angular variables Roll *(ϕ),* Pitch *(θ),* and Yaw *(ψ)* is decided by a right handed rotation rule for positive x, y and z axes, respectively. The tilt angle μ is measured by y-z coordinate axis (Yoon, 2013, Chiou, 2013).

Dynamics of motion

The triple tilting rotor UAVs has three rotorcrafts speed and one tilt angle as four inputs and based on Newton-Euler mathematical formulation is presented with six Degree of Freedom (DOF). Tricopter has similarly to conventional helicopter control commands: collective, longitudinal, lateral and yaw or pedal control (Chiou, 2013, Budiyono, 2007). They are denoted as δlat (Roll control), δlon (Pitch control), δped (Yaw control) and δcol (collection). Since two front rotors are maneuvered in different speed, the Roll (φ) control is created, such as when speed of rotor 1 is down and rotor 2 up to make the UAV toward the left and vice versa. When the velocity of third tail rotor is changed, the Pitch (θ) control is generated. By varying the tilt angle μ, the Yaw (ψ) control is occurred. This model is shown in Figure 1 and Table 1 is the Tricopter notations.

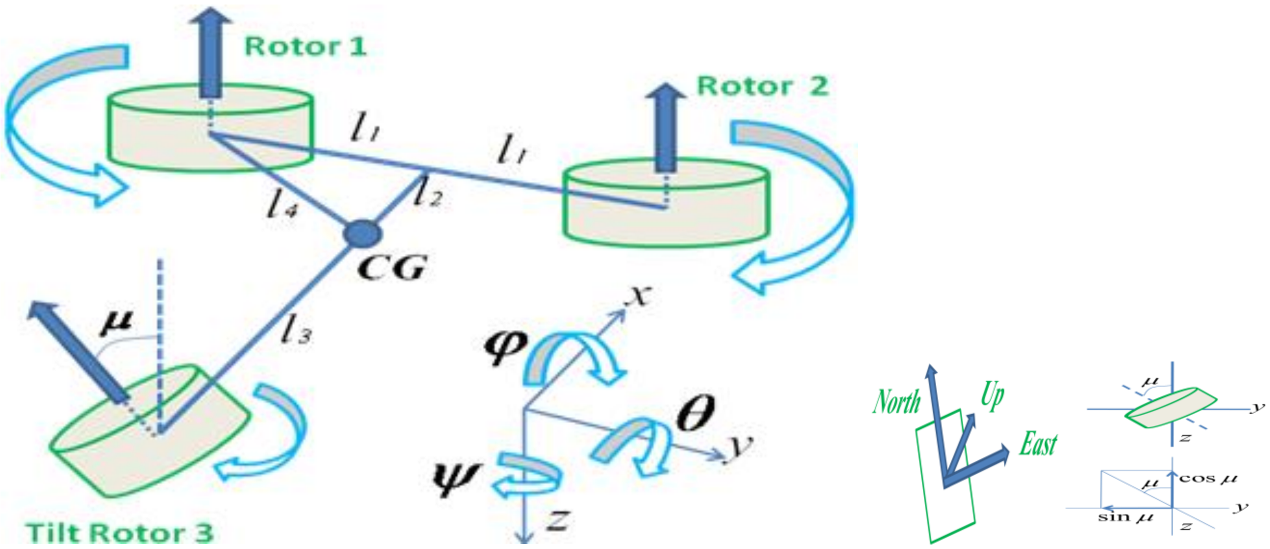


Figure 1. Tricopter configuration in 3D coordinate frame

Table 1. Tricopter UAV model notations

F_X, F_Y, F_Z	The external forces
L, M, N	The external moments
(u, v, w)	The translational velocities
(p, q, r)	The rotational velocities (angular velocities)
(ϕ, θ, ψ)	The rotational angles (Roll, Pitch, Yaw)
(I_{XX}, I_{YY}, I_{ZZ})	The rotational inertias

WAYPOINT TRACKING AND MOTION FLY PATH PLANNING

Waypoint tracking

The waypoints are helped to define invisible routing paths for advanced navigational systems such as the Global Positioning System (GPS) (Suzuki, 2013), in which the users would easily monitor the vehicle position. The autopilot controllers tune autonomous flight waypoint tracking in preparation for advanced navigation research. A track inside the flight test range is generated by the waypoints that are built in list:

$$W = \begin{bmatrix} w_{1_x} & w_{1_y} & w_{1_z} \\ w_{2_x} & w_{2_y} & w_{2_z} \\ \vdots & \vdots & \vdots \\ w_{m_x} & w_{m_y} & w_{m_z} \end{bmatrix} \quad (1)$$

A path following converges with the desired path by means of a "Helix moving strategy" that is kept in track of its progress. The Tricopter, in this project refers to survey longitude, latitude and altitude coordinate.

Motion fly path planning

UAVs flight route is planning for surveillance mission. In this section, the motion fly path is introduced as reference setpoints of flying motion control. Helix path planning is generated from two fundamental government moving equations in which Pitch motion r_1 and Yaw motion r_2 are simultaneously occurring. Due to the composition of the disturbance wind attached to the system in gradual blow, the Helix spiral fly path motion (also called Descending spiral trajectory) is created by adding a k coefficient during the operation time $k = \mathrm{e}^{(-t/18)}$. The Helix fly path motion equations:

$$\begin{cases} R_1 = k.*\sin(t) \\ R_2 = k.*\cos(t) - \pi/3 \\ Z = Z(t) \end{cases} \quad (2)$$

ADVANCED CONTROL STRATEGIES

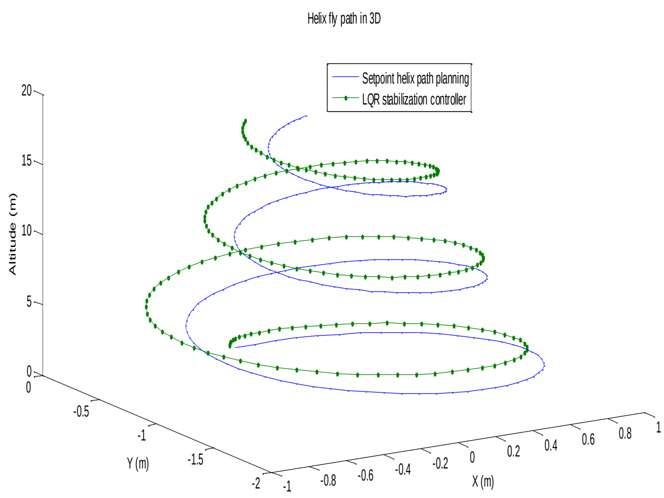
Stabilization LQR controller

The Tricopter system must be asymptotically stable and maintain the stabilized flying motion during all of the operation time. A system is stabilized if there exists a state feedback control $u(t) = -kx(t)$ such that the closed-loop system is exponentially stable (Chiou, 2013).

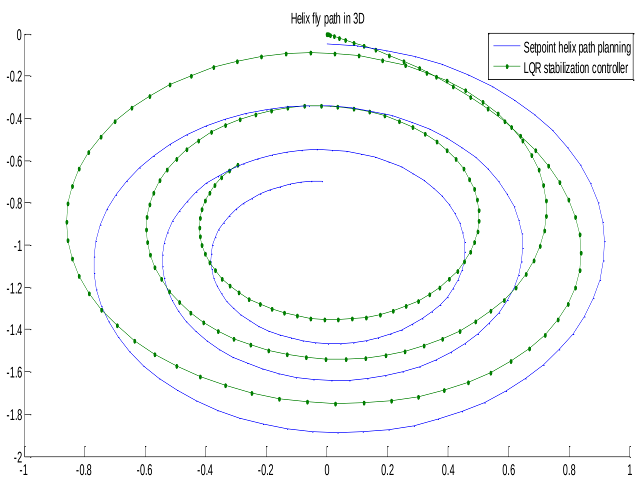
Next, the Riccati equation $A^TP+PA+Q-PBR^{-1}B^TP=0$ is one of solutions for the feedback gain matrix K. If $K=-R^{-1}B^TP$, then the closed-loop system is asymptotically stable. Thus, the Linear Quadratic Regulator controller gain is applied to warrant and maintain the system stability. Figure 2 shows the stabilization of LQR flying motion control performances. However, the flying path motions are not in high precision.

Fuzzy logic Controller

The FLC dynamic behavior, which is based on expert knowledge, is characterized by a set of linguistic rules (Fu, 2013, Chiou, 2013, Passino, 1998, Suzuki, 1992, Mandani, 1977, Felicia, 2015). The input variables are error $e(t)$ and error rate $de(t)/dt$ and the output is ci. Thus, fuzzy relationship between e, de and ci are figured out. Hence, ci can be changed on line according the rules, current error and error rate. The Inputs and Output of fuzzification interface are showed in Figure 3.



(a) Helix flight path in 3D



(b) Helix flight path in 2D

Figure 2. Helix flight path planning

The Mandani's MIN–MAX inference engine type and center of area method (COA) defuzzification are employed in this paper. Since its combination yields the basic implementation parameters of the fuzzy control algorithm, the seven linguistic triangular membership functions assigned for input and output variables are: negative big NB (-3), negative medium NM (-2), negative small NS (-1), zero ZE (0), positive small PS (1), positive medium PM (2) and positive big PB (3). The fuzzy controller rule table is explained in Table 2.

GA, as education software, optimal Fuzzy Controller scaling factors

The GA optimization method is chosen for the purpose of optimizing the scaling factor (SF) gains of the PD like Fuzzy controller. In the controller schematic as shown in Figure 4, the fuzzy inference system inputs are the tracking error *e(t)* and the differential tracking error *de(t)*. In a PD like Fuzzy structure P (Proportional gain) is denoted by G_e and D (Derivative gain) is denoted by G_d. Genetic Algorithm Optimization (GAO), which remains as one of the most widely used optimization algorithms in modern nonlinear optimization (Yang, 2010, Antunes, 2014), is reliable and robust for searching solution spaces.

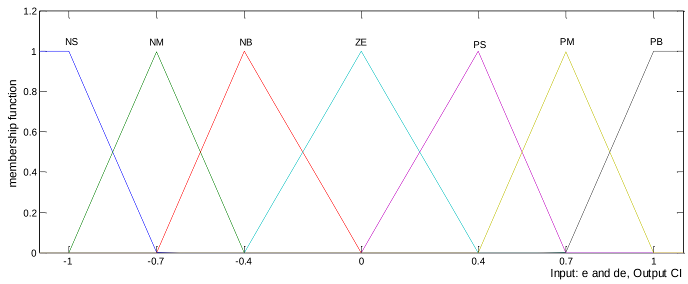


Figure 3. Fuzzification interface: input e and de, output CI

Table 2 Rule table of fuzzy logic controllers

CI(t)					***e(t)***			
		-3	**-2**	**-1**	**0**	**1**	**2**	**3**
	3	*0*	1	2	3	3	3	3
	2	-1	*0*	1	2	3	3	3
	1	-2	-1	*0*	1	2	3	3
de(t)	**0**	-3	-2	-1	*0*	1	2	3
	-1	-3	-3	-2	-1	*0*	1	2
	-2	-3	-3	-3	-2	-1	*0*	1
	-3	-3	-3	-3	-3	-2	-1	0

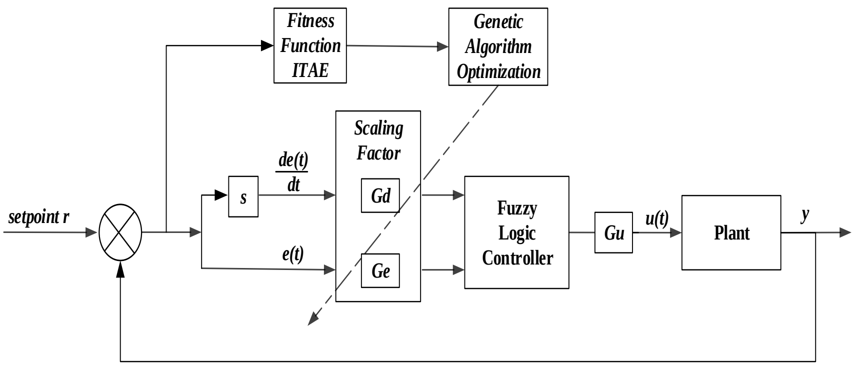
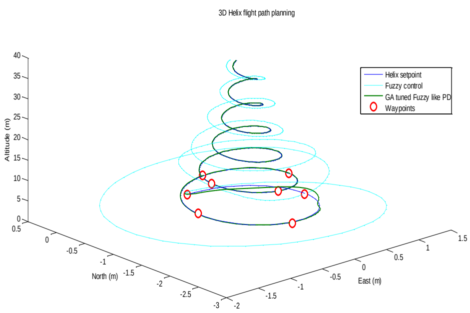


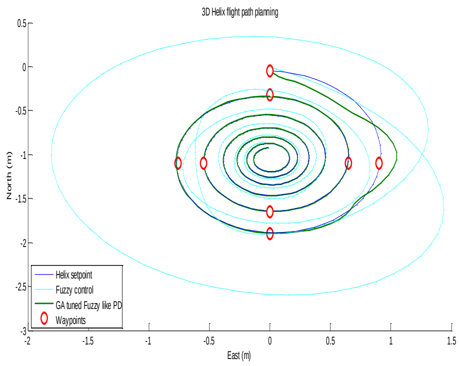
Figure 4. The GAO-FLC controller schematic

Table 3. Tricopter simulation parameters

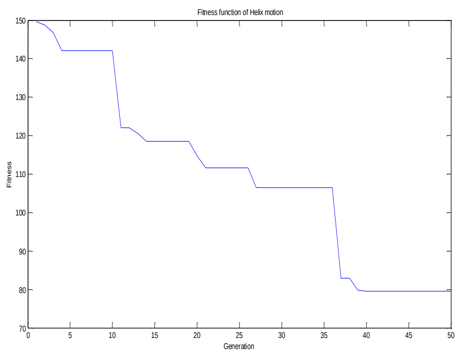
Notation	Parameters (unit)
I_{xx}	0.0057211 kg.m^2
I_{yy}	0.073933 kg.m^2
I_{zz}	0.012545 kg.m^2
$b_1 = b_2 = b_3$	0.00013678 N.s^2
$d_1 = d_2 = d_3$	0.000024323 N.m.s^2
l_1	0.19 m
l_2	0.122 m
l_3	0.23 m
l_4	$\sqrt{l_1^2 + l_2^2} = 0.225m$
m	0.84 kg



(a) Flight path planning in 3D view



(b) Flight path planning in top view 2D



(c) The fitness function

Figure 5. Helix flight path planning

The Genetic Algorithm optimized Scaling Factors procedure is illustrated as following:

-Set multi-objective function $g(x) = G_e .e + G_d .de$, $x = \{G_e, G_d\}$
-Encode the solution into chromosomes (binary strings)
-Identify fitness function f_{min} *(ITAE)*
-Create the initial population
-Initial probabilities of crossover (*pc*) and mutation (*pm*)
-*While* (N<Max number of generations)
-Produce new solution by crossover and mutation
If pc>rand, Crossover; *end if*
If pm>rand, Mutate; *end if*
-Accept the new solutions if their fitness decrease
-Pick up the best current for new generation (elitism)
-*End while*
-Decode the results and visualization

The main of Genetic Algorithm pseudo code is

[x,fval] = ga(FitnessFunction,Nvar,UB,LB, fmin) is set *[G_e,G_d,f] = ga(ITAE,2,100,0, fmin)*

Due to minimization of ITAE fitness function, the proposed controller GAO-FLC accomplishes the superior tracking performance over standard FLC, especially its adaptability to counteract environment disturbances and guarantee global asymptotic stable. Additionally, the robustness of waypoint tracking and motion fly path planning are in high verification. The ITAE performance index is mathematically given by:

$$ITAE = \int_0^\infty t\left|e(t)\right|dt \qquad (3)$$

SIMULATION RESULTS

The GAO-FLC proposed controller simulation parameters are set on 50 generations of the number of population generation. The GAs crossover rate is *pc = 0.85* and mutation rate *pm = 0.001*. The Scaling factor inputs G_e and G_d, is set in range ϵ [0, 100], the scaling factor output is set as 1. In the Helix flight path planning The SF gains after tuning by GAO method are G_e = 48.325, G_d = 9.836.

The waypoints in advanced navigational systems (GPS), which are used to identify invisible routing paths for easily monitoring position, are pointed in significant nodes around the flying paths on each 90 degrees.

The compared controller strategies are investigated, the first is Fuzzy controller, the second is GAO-FLC optimized SF gains controller. The path following trajectory is proved by the node of waypoints. The trajectory tracking results indicate obviously that the proposed controller (GAO-FLC) has achieved the best flight performance.

CONCLUSIONS

This study has developed the flight motion controller strategies. The numerical simulations flight path planning is generated by the popular motion: Helix flying path. The LQR controller was used to verify the controllability and stability of the single tilt Tricopter movements. In the demonstrated results, the FLC performed well in the assessment of the following waypoint tracking and flight motion. We, then successfully applied the Genetic Algorithm Optimization as the education software to optimize Fuzzy Scaling Factor via ITAE criteria for the Tricopter flight motion control system. The proposed controller software illustrated superior and the highest accurate tracking trajectory overwhelming the standard FLC. It is especially adaptive and able to counteract environmental disturbances while guaranteeing global asymptotic stability and system robustness.

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