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Comparison of Fuzzy and PID control of Kite Generator System

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Abstract: One of the most important sources of energy that can be easily transmitted to other types is electrical energy. Power generation can be carried out using fossil fuels or renewable sources. Since, non-renewable energy sources are exhaustible and pollute the environment, renewable energies are expanding rapidly in recent years. Wind power can be considered as a renewable energy and kites can be used to generate electricity using wind energy. Therefore, kite control in different ways and also kite height control are important. In this paper, a case study is carried out on a dynamical model of a kite generator and its closed-loop simulation is assessed in MATLAB software environment using PID and Fuzzy controllers and performance is studied in different wind speeds.

Keywords: Renewable Energy, Kite Generator, Fuzzy Controller, PID Controller

1. Introduction

Recently, wind energy has emerged as a major part of electricity generation mix. Also, different limitations on heights of turbine hub, blade lengths and location restrictions regarding permission and environmental issues including special areas of social and conservation acceptance based on noise and visual impacts makes the ground-based wind turbine systems to be more constrained. So, great attention has been paid to high altitude wind harness, as tethered kites, dirigible based rotors and air foils. The aforementioned technologies are able to generate high electricity capacities since they operate above the neutral atmospheric boundary layer of 1300m and are designed to be subject to more persistent and powerful winds [1].

Among recent technologies for electricity production from renewable resources, in [2] a novel class of wind energy converters is introduced as Airborne Wind Energy System (AWES).Also, flying tethered wings or aircrafts are used by AWES to reach winds blowing at atmosphere layers inaccessible by traditional wind turbines. In this regard, a variety of systems are analyzed and tested and several prototypes are developed.

In [1] high altitude wind power is studied and the technical and economic viability of high altitude wind power deployment is investigated in Northern Ireland as a resource. Also, the optimal locations are identified considering geographical constraints and wind data. In [3] wind load effect is analytically modelled on a tether which constrains a power kite with fast crosswind motion. The crosswind motion law is then generalized for kite control and is derived in case of kite equilibrium motion. In [4] a closed-orbit kite generator system (KGS) is studied and controlled. The system is considered as a kite with orientation mechanism and power transformation system. Also, the optimal value of tether's length rate variation and orbit's period are obtained. In [5] wind energy production is accomplished using kite traction force. In [5], the energy produced by kite is controlled whichrenders safe kite fly in case of strong wind gusts. In [6] KiteGen is studied as a wind energy generator which employs power kites to capture high altitude wind power. In [6], a kite model including kite aerodynamic characteristics and the line weight and drag force effects are used to describe system dynamics. Also, the energy obtained by KiteGen is maximized and the input and state constraints are satisfied by employing model predictive control scheme and set membership function approximation theory. In [7], Direct-Inverse Control approach is designed using a sparse identification method which is employed to control High-Altitude Wind Energy (HAWE) generators. It allows direct controller computation from data and so avoids system model derivation.

Since kite height control in different conditions of wind speed is highly important, so in this paper, fuzzy and PID controllersare designed to control the system in different wind velocities.

The rest of the paper is structured as follows: modelling the kite generator systemis stated in Section 2, controlling the kite generator system using PID controller and fuzzy controller are presented in Sections 3 and 4, respectively, simulation results are given in Section 5 and finally the paper is concluded in Section 6.

2. Modelling the kite generator system

The wind speed vector is shown as$W_t = W_0 + W_t$, where W_0 is the nominal wind speed and W_t is a wind speed which creates turbulence measured for wind with components in all directions.It is considered unknown:

$W_0 = (\frac{W_x(Z)}{0\ 0})$ (1)

Where $W_x(Z)$ is a known function which indicates the nominal wind speed at altitude Z.

As shown in Figure1, the position of kite is expressed as a function of distance from the origin and angles. In this figure, three unitary vectors are shown for the local coordinate system around the kite gravity centre.

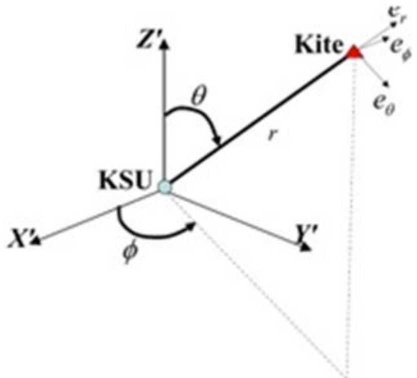


Fig. 1 Kite generator model

By applying Newton's motion law in the coordinate system, the dynamical equations are obtained as follows:

(1) $\ddot{\theta} = \frac{F_\theta}{mr} \times u_\theta \; \ddot{\phi} = \frac{F_\phi}{mr\ \sin\ \theta} \; \ddot{r} = \frac{F_r}{m} \times u_r \times u_\phi$

Where m is the kite mass and F_r, F_θ and F_ϕ include the components of the kite gravity force, the appearance forces, aerodynamics and drag aerodynamic which are as follows in the local coordinate system [3]:

(2) $F_\theta = F_\theta^{grav} + F_\theta^{app} + F_\theta^{aer} + F_\theta^{c,aer} \; F_\phi = F_\phi^{grav} + F_\phi^{app} + F_\phi^{aer} + F_\phi^{c,aer} \; F_r = F_r^{grav} + F_r^{app} + F_r^{aer} + F_r^{c,aer} - F^{c,trc}$

There exist 6 state variables in the kite generator system r , φ, θ, $\dot{r}$, $\dot{\phi}$ and $\dot{\theta}$. Also, the system has three inputs as ur, θu and φu, and three outputs as r, φ, and θ.

3. Controlling the kite generator system using a PID controller

The traditional PID control is still the most commonly used controller for systems.It is simple in algorithm and it has good stability and high reliability [9]. In this section, PID controller is used to control the kite generator system.The PID controller transfer function is as follows:

(3) $G(s) = K_p + \frac{K_i}{s} + K_d s = \frac{K_d s^2 + K_p s + K_i}{s}$

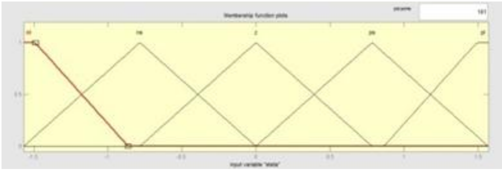
Where K_i , K_p and K_d are the integral,proportional and derivative coefficients, respectively. It is necessary to set K_i , K_p and K_d coefficients. In this paper, Zigler Nichols algorithm is applied to set the aforementioned parameters.

In this regard, the values of K_i , K_p and K_d for θ control are obtained as 50.2745, 10.4623 and 80.2467, respectively, for φ control, 76.5463, 20.8735 and 95.7457, respectively.

4. Controlling the kite generator system using fuzzy controller

Fuzzy logic represents a sort of imprecise knowledge common in natural systems which allow both partial and multivalued truths [10]. It is specificallysuggestedfor problems which cannot be easily represented by mathematical models due to either problem complexity or the fact that data is incomplete or unavailable. Fuzzy systems are based on information fuzzy coding which operate with fuzzy sets, and a fuzzy model can be considered as a framework which is based on the concepts of fuzzy sets, fuzzy if-then, and fuzzy reasoning. Fuzzy systems include the input variable fuzzification, the inference or rule firing, and the controller output variable de-fuzzification[11].

In this paper, the error value and the error derivative of θ and φ is considered in $[\frac{\pi}{2}, -\frac{\pi}{2}]$ and $[\pi, -\pi]$, respectively.Also, the error value and the error derivative is considered in [200, -200] and [100, -100], respectively. Figure 2 shows the error and the error derivative membership function for θ and φ, and Figure 3 shows the error and error derivative membership function for the rope length and Table (1) demonstrates the set of rules.



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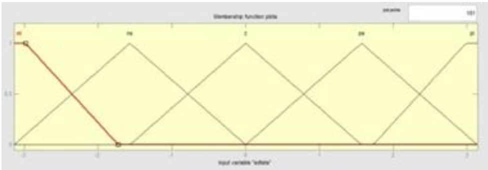

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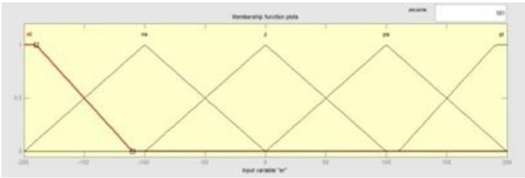
Fig. 2(a) the error membership function for θ and φ, (b) the error derivative membership function for θ and φ



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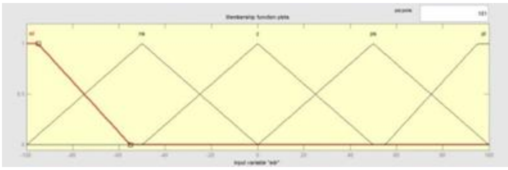

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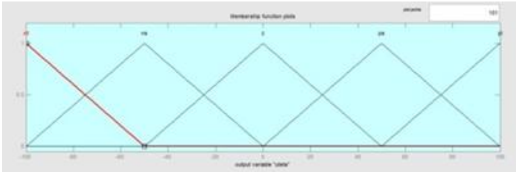
Figure 3. (a) Error membership function for r, (b) Error derivative membership function for R

Table 1. Fuzzy controller rule sets

OutputController		Error of angle θ				
		NL	NS	Z	PS	PL
Error derivative of angle θ	NL	NL	NL	NL	NS	Z
	NS	NL	NL	NS	Z	PS
	Z	NL	NS	Z	PS	PL
	PS	NS	Z	PS	PL	PL
	PL	Z	PS	PL	PL	PL
OutputController		Error of angle φ				
		NL	NS	Z	PS	PL
Error derivative of angle φ	NL	NL	NL	NL	NS	Z
	NS	NL	NL	NS	Z	PS
	Z	NL	NS	Z	PS	PL
	PS	NS	Z	PS	PL	PL
	PL	Z	PS	PL	PL	PL
OutputController		Error of kite height r				
		NL	NS	Z	PS	PL
Error derivative of kite height r	NL	NL	NL	NL	NS	Z
	NS	NL	NL	NS	Z	PS
	Z	NL	NS	Z	PS	PL
	PS	NS	Z	PS	PL	PL
	PL	Z	PS	PL	PL	PL

Here, the controller output is the force applied to kite in the direction of the θ and φ, and also the force applied to the rope. Also, the output interval for θ and φ is [100, -100] and the rope's force is in [1500, -1500] interval.The control signal membership function for θ, φ and r is presented in Figure 4.



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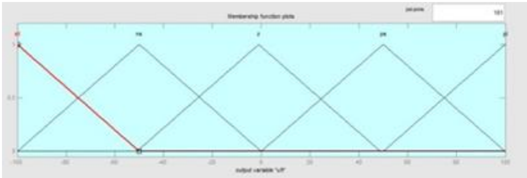

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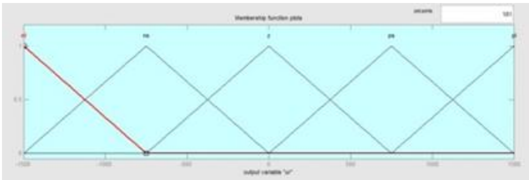

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Figure 4 (a) Control signal membership function to control θ (b) Control signal membership function to control φ (c) Control signal membership function for kite height control

5. Simulation Results

In this section, the performance of kite generator system is evaluated in case of using fuzzy and PID controllers.

Figures 5,6 and 7 showθ , φ and*R*in PID and fuzzy controllers where the reference input for θ , φ and *R* are 30 degrees, 60 degrees and 200 meters, respectively.

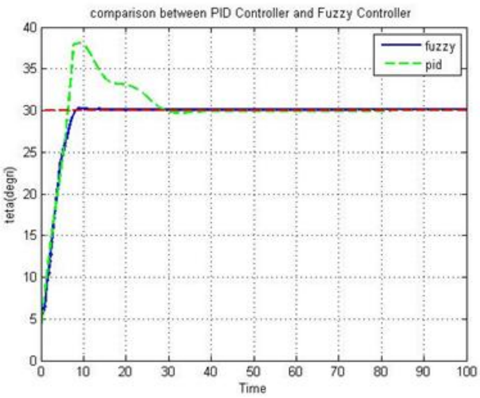

Figure 5. θ in kite generator system using fuzzy and PID controllers

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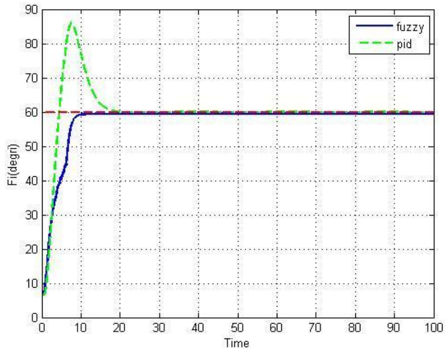

Figure 6. φ in kite generator system using fuzzy and PID controllers

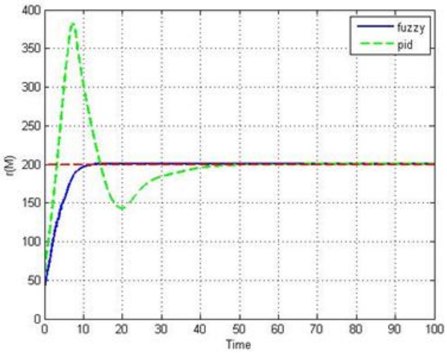

Figure 7. *R* in kite generator system using fuzzy and PID controllers

In order to evaluate the performance of our system using fuzzy and PID controllers, the system is exposed to wind at different velocities. Figure 8 shows thewind speed profile and Figures 9.10 and 11 show θ , φ and *R* in kite generator system using PID and fuzzy controllers in case of exposure to varying wind speed.

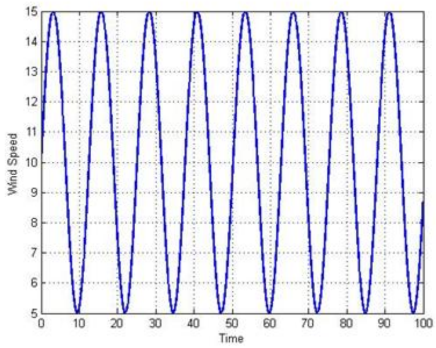

Figure 8. The windspeed profile

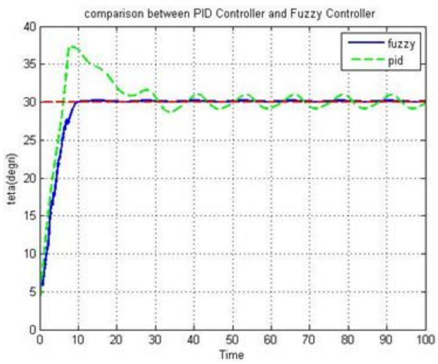

Figure 9.θ in kite generator system using fuzzy and PID controllers in case of variable wind speed

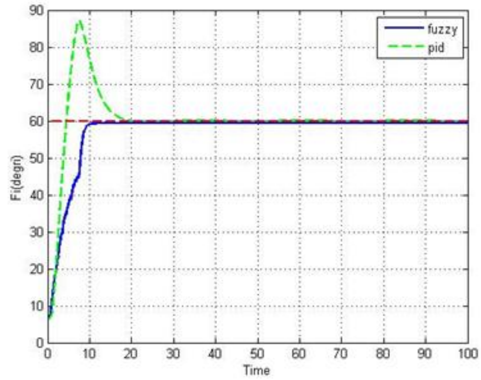

Figure 10.φ in kite generator system using fuzzy and PID controllers in case of variable wind speed

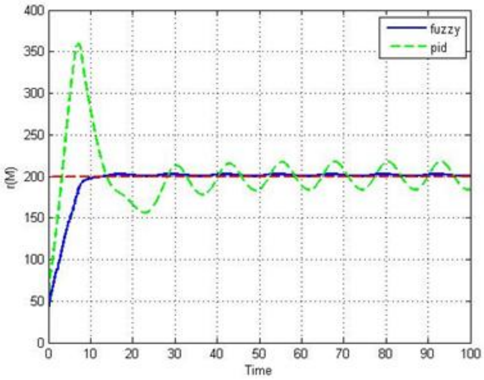

Figure 11. *R*in kite generator system using fuzzy and PID controllers in case of variable wind speed

The overshoot and settling time in kite generator system using PID controller is 23% and 30 seconds for θ ,43% and 18 seconds for φ and 91% and 48 seconds for *R.* However, the overshoot and settling time in kite generator system using fuzzy controller is 2% and 8 seconds for θ,0% and 10 seconds for φ and0% and 14 seconds for *R*.So, it can be concluded that the fuzzy controller renders superior performance comparing with the PID controller in kite generator system in case of overshoot and settling time.

6. Conclusion

In this paper, kite generator control is accomplished based on Yoyo model and in this regard fuzzy and PID controllers are used.It is shown that the fuzzy controller is able to control the kite at the desired point by changing the wind speed in a wider range and it can withstand wind speedchanges in the range of 5 to 15 m / s. So, applying fuzzy controller in kite generator system renders superior performance in case of settling time and overshoot comparing with PID controller.

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