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ScienceDirect

Energy Procedia 90 (2016) 349 – 359

Energy Procedia

5th International Conference on Advances in Energy Research, ICAER 2015, 15-17 December 2015, Mumbai, India

Utilization of wind shear for powering unmanned aerial vehicles in surveillance application: A numerical optimization study

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Abstract

Dynamic soaring is the rationale behind the prolonged flights of a seabird Albatross. It involves utilization of energy from the wind shear present near the earth surface. Small unmanned aerial vehicles (UAVs) can be kept loitering without any external power input by dynamic soaring. In this work, dynamic soaring is used to power UAVs for the surveillance application. A set of 6-DoF point mass equations governing the aircraft motion is used in the optimal control problem formulation. Appropriate constraints considering the material properties of a UAV, and the loiter pattern of dynamic soaring, are imposed on state variables and control parameters. Trajectories are optimized by using GPOPS-II, MATLAB based optimal control software. The problem is optimized for the efficacy of area under surveillance. Variation in the surveillance area is analyzed with the change in the view angle of camera, wind strength, and nature of wind shear profile. Surveillance by dynamic soaring becomes effective with the increase of wind strength and also with the change of wind shear profile towards the logarithmic variation. The minimum requirement of wind strength to perform dynamic soaring has been identified by considering various wind shear profiles. Finally it is concluded that small UAVs (comparable with the size of Albatross) can be constantly kept on surveying using wind energy as the sole power source, as long as free stream wind velocity is greater than the minimum requirement for dynamic soaring.

Peer-review under responsibility of the organizing committee of ICAER 2015

Keywords: Wind energy; Dynamic soaring; Optimal control algorithm; Trajectory optimization for surveillance

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Peer-review under responsibility of the organizing committee of ICAER 2015
doi:10.1016/j.egypro.2016.11.202

1. Introduction

Wind shear near the earth surface is effectively used by seabirds to fly thousands of kilometres without flapping of wings. It can be very useful for the UAVs meant for prolonged surveillance. Mission capabilities of UAVs are mainly limited by their inability of carrying sufficient fuel. Although improvements of battery technology can enhance their capabilities, immediate performance gains can be obtained by energy utilization from the atmosphere. There are several ways to extract energy from atmosphere and dynamic soaring is one such a technique. Energy extraction from the wind shear present near the earth surface is referred as dynamic soaring. The primary objective of this paper is to demonstrate the propulsion of small UAVs by dynamic soaring through simulations, considering surveillance application.

Constant surveillance is required for many applications such as patrolling, monitoring shipping lanes, commercial fisheries etc. In many potential civilian and military UAV missions, the power requirements reduce their range and endurance, diminishing their utility. As a consequence, UAVs have become primarily limited to short range observation missions. There is a plenty of energy available in the atmosphere where UAVs fly. This energy can be useful to increase their range and endurance. If an aircraft is able to extract kinetic or potential energy from soaring flight, the consumable energy carried on board in the form of batteries or fuel would last considerably for prolonged period, thereby increasing their range or endurance. Capabilities of small UAVs can be increased significantly by utilizing the wind energy present in surrounding ambience in the form of wind shear.

Rayleigh [1] is known to be the first person to propose that energy extraction is possible in a horizontal but non-uniform wind field. After him, many scientists, specifically Turcker and Parrott [2], Weimerskirch et al [3] worked on this subject. Gradually theory of dynamic soaring was evolved. In early 2000s to 2010s, computational algorithms on optimal control were developed rapidly. Sachs [4] found the optimal trajectory for minimum wind

Nomenclature

A	wind shear parameter
AR	aspect ratio (= b^2/S), m
CD_0	parasite drag coefficient
C_L	coefficient of lift
C_D	coefficient of drag
β	average slope of wind shear over [0, h_{tr}], s^{-1}
μ	banking angle, clockwise from backside of glider, degree
ψ	heading angle, measured clockwise from north, degree
ρ	density of air, kg/m^3
γ	flight path angle relative to air, degree
V	velocity of glider, m/s
K	induced drag factor
S	wing area of glider, m^2
m	mass of glider, kg
g	acceleration due to gravity, m/s^2
n	load factor of glider
x, y	east and north position of glider, m
z	altitude of glider, m
W_z	wind velocity variation with altitude, m/s
W_{max}	maximum wind velocity, m/s
h_{tr}	boundary layer thickness, m
L	lift force, N
D	drag force, N
θ	view angle of camera mounted on UAV