Minimum-time approach to obstacle avoidance constrained by envelope protection for autonomous UAVs

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ABSTRACT

An integrated approach is needed for combining path planning for obstacle avoidance with envelope protection to ensure that a UAV is operated within its safe operational limits while maneuvering in obstacle fields. This paper presents a minimum-time approach to this problem by treating obstacle avoidance and envelope protection as inequality constraints in a state space formulation. The approach is used to study the guidance of a rotary wing UAV for aggressive maneuvering in avoiding an obstacle while staying within its operational envelope. The Nonlinear Trajectory Generator (NTG) is used as a real-time optimization solver, and load factor and rotor flapping angle are considered as limit parameters. A nonlinear simulation model of a rotary wing test bed within the Georgia Tech Unmanned Aerial Vehicle Simulation Tool (GUST) is used to evaluate the proposed approach.

1. Introduction

Unmanned aerial vehicles (UAVs) are expected to play an increased role in both civil and military applications. The applications include observation, surveillance, and reconnaissance, etc. [1,2]. A principal reason for the interest in UAVs is the desire to reduce the risk to humans, but it also is to perform missions in a more efficient and less costly fashion than has historically been the case with manned vehicles. A related reason is that freeing machines from the limitations imposed by humans would increase their performance. Since UAVs are expected to operate in unknown and adversarial environments, issues on their safety need to be investigated extensively. The vehicle safety may be endangered in two different ways: external hazardous objects and internal performance limitations.

The mission environment may contain obstacles and zones that the vehicle is not allowed to enter and may not be fully characterized at the start of a mission. Obstacles may be detected as the vehicle moves through the environment or their locations may change over time. There have been numerous studies on online trajectory planning for obstacle avoidance. The various approaches to obstacle avoidance problem can be categorized as heuristic methods [3–6] and optimization based methods [7–11]. In general, heuristic approaches handle uncertainties in a robust manner, while optimization based approaches provide a best solution with respect to a given performance index. In [12], a potential field approach for obstacle avoidance is combined with an optimization based trajectory generation using a model predictive control (MPC).

Another important task of the 'built-in intelligence' in autonomous UAVs is to monitor their health and prevent flight envelope violations for safety. A UAV health condition depends on its aerodynamic loading, actuator operating status, structural fatigue, etc. Any technique to maintain specific flight parameters within the operational envelope of a vehicle falls under envelope protection [13–15]. Even though a key feature of envelope protection is to identify a relationship between operational limits and command/control inputs, it is difficult to obtain an exact analytic expression for the relationship. Consequently, artificial neural networks (ANNs), for example, are implemented to approximate the relationship by online or offline training. Furthermore, since it is expected that UAVs will be operated more aggressively than their manned counterparts, envelope protection is very important in UAVs, and must be done automatically due to the absence of a pilot.

As noted above, the problem of obstacle avoidance and envelope protection for UAV autonomy have been considered separately. Certain mission tasks may result in aggressive maneuvering through obstacle fields, and it is imperative that the flight envelope of a UAV is protected to ensure safety and structural integrity. In addition, it is also desired that interruption of the original flight is minimized from a mission effectiveness point of view. The conflicting requirements of aggressive maneuvering for obstacle avoidance and the restricted maneuvering for envelope protection require new methods that combine obstacle avoidance and envelope protection into a unified framework.