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Data-driven Risk Assessment and Multicriteria Optimization of UAV Operations

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***Abstract*—This paper introduces a novel data-driven risk metric and assessment method for UAVs operating in environments typically encountered in civilian applications. A truly “data-driven risk measure” is derived through a probabilistic formulation that not only accounts for the intrinsically stochastic nature of the considered environmental factors (such as weather and signal strength), but also incorporates extrinsic prediction uncertainties originating from the geographical sparsity of data collection sources. We present a data-driven modeling of the stochastic environmental factors using Gaussian process-based function approximations. Notably, the proposed mathematical definition of the risk metric is based on the probabilistic predictions of such a Gaussian process model and introduced through a path-integral formulation. The problem of minimizing operational risk for multiple UAVs in partially unknown environments is then defined in a multicriteria optimization framework to address the trade-off between the path-integral risk measure and classical path-efficiency (distance). We show that such approach can be embedded into current standard risk assessment methods which could be easily integrated into UAVs traffic management initiatives. We analyze the results through a number of simulations, including realistic scenarios.**

***Index Terms*—Risk metric, risk assessment, probabilistic analysis, unmanned aerial systems, air traffic management, path planning.**

I. Introduction

RECREATIONAL and commercial use of unmanned aerial vehicles (UAVs) in public airspace is increasing dramatically. Regulations, driven by safety concerns, have been a significant barrier to a more widespread use of UAVs. However, new regulations by the Federal Aviation Administration (FAA) for non-recreational use of UAVs in the United States [1], effective August 2016, represent a milestone as they lower the barrier to entry for new users and are expected to significantly increase the number of units in the sky. Other countries are likely to adopt similar laws in a near future. As UAVs usage increases, new risk exposures emerge which could result in multi-million dollar claims. Accidents happen regardless of technological sophistication or operator skills. Two priority safety concerns raised by UAVs include mid-air collisions and loss of control [2]. Collisions may occur if the pilot cannot see and avoid other (manned or unmanned) aircraft in time, whereas loss of control can result from diverse factors such as system failure, flying beyond signal range (e.g. radio, WiFi or GSM networks) or environmental conditions (e.g. bad weather or bad GPS reception). Whereas mid-air collisions can be largely avoided by operational planning and sense and avoid systems, loss of control situations are stochastic in nature and a proper risk assessment approach needs to be brought into place to minimize the occurrence and severity of such situations.

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Risk needs to be brought into the perspective of current UAVs traffic management systems. In particular, a UAVs traffic management system must be equipped with predictive and prescriptive abilities to evaluate the environment and operation, and provide a recommendation that, eventually, minimizes risk. There exists a variety of actors developing different alternatives to enable safe and efficient low-altitude operations. One of the most remarkable examples is NASA’s UAS Traffic Management (UTM) system [3]. One key characteristic of the UTM system is that it will not require human operators to monitor every vehicle continuously, but will provide human managers with the data to make strategic decisions. Whereas much data can be found in the public domain, there is a need of adopting state-of-the-art technologies to automate the analysis of this data and provide valuable insights to enable the predictive and prescriptive abilities mentioned above and ease the strategic decisions taken by human operators.

A. Related work

Safety risk assessments for UAVs operations have been largely derived from safety risk assessments for manned aircraft operations [4]. These risk assessments have been traditionally focused on defining safety risk probabilities and safety risk severities according to some likelihood and severity categories, respectively. Such categories do not fully exploit the available amount of data which allows to define risk probabilities and risk severities via probability distributions in a more precise manner. Some drawbacks of these approaches are described in [5]. Moreover, risk mitigation actions are defined according to some acceptance levels and recommended actions are subsequently defined such that operations are within acceptable operational risk limits [6], [7]. Defining such broad categories and operational limits may prevent safe operations from being executed and, therefore, a quantitative framework which allows for some risk metric minimization could be a more efficient approach. The reasons above motivate the definition of a probabilistic data-driven risk metric which can be used to define and maximize the safety degree of a particular operation.

Probabilistic risk metrics have been defined in the literature for different type of vehicles [8]–[10]. [11] introduces an approach to risk assessment of UAVs as the summation of the