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Risk Assessment of Flight Paths for Automatic Emergency Parachute Deployment in UAVs

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Abstract: This paper presents models for the risk assessment and generation of flight paths, which support the automatic deployment of emergency parachutes for unmanned aerial vehicles in emergencies due to loss of propulsion. Based on a risk analysis of the area underneath the flight path, suitable deployment positions are identified, which minimize the chance of endangering humans on the ground, property damage and loss of the air vehicle. Additionally, the flight path selection is guided by constraints, such as control data link availability or aircraft performance.

Keywords: UAV, Decision making, Autonomy, Emergency planning, Trajectory generation

1. INTRODUCTION

The operation of an unmanned aerial vehicle (UAV) exhibits a significantly higher accident rate compared to piloted aircrafts (Loh et al. (2009)). This poses severe limitations on the possible adoption of unmanned systems particularly in the civilian air space. Hence, one important challenge is the implementation of technologies which can deal gracefully with failures and ensure safe operation even in the event of engine loss. In ultralight aviation emergency parachutes have become an important tool to avert damages and casualties caused by aircraft failures.

An ultralight aircraft with good glide performance can offer substantial range even without active propulsion. This enables the execution of maneuvers to support the deployment of the parachute and improves the chance of a safe landing. However, the risk analysis for an unmanned system is fundamentally different from the risk analysis for a piloted aircraft. The main goal is not to endanger humans and limit damages on the ground. The survival of the UAV itself has a lower priority. Therefore, the approach presented in this paper takes the landing area into account for the risk analysis. Due to the strong influence of the wind, the deployment of a parachute results in a high uncertainty regarding the landing position on the ground. In order to mitigate the effects of the wind on the descent trajectory safe deployment positions at low altitude above ground level are identified.

The research presented in this paper was conducted in the EUROPAS project. The goal of this project is the development of an optionally piloted aircraft for civilian applications, such as acquiring a situational overview during natural disasters or infrastructure monitoring.

In this paper we present ongoing work for risk assessment and parachute deployment position identification and selection. The main contributions are:

- A distributed decision making architecture to reduce processing requirements onboard the UAV (Sec. 3)
- Map-based risk assessment of human casualties, damages on the ground and air vehicle loss (Sec. 4.1)
- Deployment position identification (Sec. 4.8) and selection (Sec. 4.9) based on simplified data link (Sec. 4.2), wind (Sec. 4.4), flight dynamics (Sec. 4.5, 4.6) and parachute descend (Sec. 4.7) models

2. RELATED WORK

Modeling the decision process of a human pilot for emergency situations is a complex task, because a high number of options need to be weighed against each other. The usual approach is a constrained 3D path planning problem (Eng (2011), Adler et al. (2012)). Meuleau et al. (2009) use the Hybrid $A^\star$ algorithm to plan an obstacle free trajectory to possible landing sites and estimate the risk based on various factors, such as the characteristics of the approach path, weather and size of the runway. Multiple options, which are classified by the computed risk, are then presented to the pilot.

If a forced landing is required, it is usually not possible to rely only on a set of stored emergency landing positions. Fitzgerald (2007) tries to identify additional sites using machine vision. Recently Scherer et al. (2012) demonstrated autonomous landing of a helicopter based on data acquired by a 3D laser scanner. Warren et al. (2013) use a downward facing camera for visual site detection. The terrain analysis is supported by a Digital Elevation Map (DEM) acquired from SRTM (Farr et al. (2007)).

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Moreover, automatic deployment of parachutes has been studied for the descent of landers on extraterrestrial planet surfaces, e.g., accurate landing for the Mars Science Laboratory mission (Braun and Manning (2006)).

3. ARCHITECTURE

The computational resources and data storage available onboard the aircraft are limited. Therefore, it is necessary to perform preprocessing tasks in the ground control station and only execute the decision making and trajectory generation in the flight management system (FMS) onboard the UAV.

Fig. 1 shows an overview of the components of the distributed decision making system. In the ground control station the map data is preprocessed and the risk estimation is computed. The resulting maps, such as the risk estimates, terrain data and link coverage, are uploaded via the data link to the FMS. In order to limit the necessary upload bandwidth, the size is restricted to the current operational area of the UAV. If the event of an unrecoverable engine loss is detected during flight, the decision making and trajectory generation is executed based on the available data.

The decision making algorithms are executed simultaneously in the ground control station and the output is visualized in the map view and presented to the remote operator. If the data link is lost, the most likely decision made onboard the UAV can still be predicted based on the last information received from the FMS. This is important to ensure situation awareness of the operator in the ground control station and facilitate the recovery of the aircraft.

The emergency planner is implemented as a hierarchical decision making system: **1.** On the first level a plausibility check based on the flight dynamics is implemented. If a minimum threshold height above ground is violated, speed limits are exceeded or the emergency trajectory generation fails, the parachute is deployed immediately. **2.** On the second level a short trajectory is generated, which keeps the ground speed low by heading into the wind and deploys the parachute. **3.** On the third level an optimized trajectory is generated to the deployment position. If the resulting flight path is not feasible due to the aircraft performance restrictions in gliding flight or the trajectory planning fails, the second level is employed as a fallback strategy.

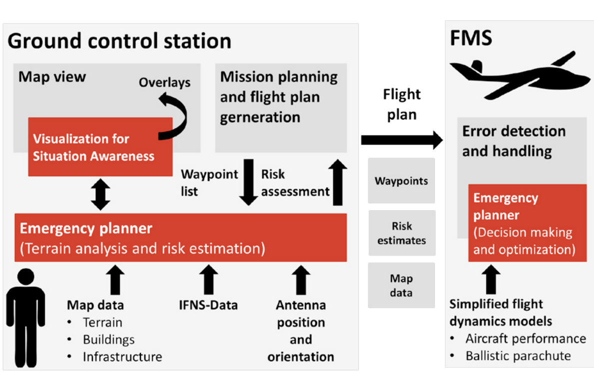

Fig. 1. Architecture of the distributed decision making system.

4. METHODOLOGY

The scenario considered in the presented work is the event of an unrecoverable loss of propulsion, such as motor failure, which limits the possible safe landing options to the activation of the emergency parachute system. However, it is assumed that the aircraft is still steerable and the gliding performance is not degraded. In this situation arises the problem of finding a suitable deployment position for the emergency parachute.

The decision making process is guided by three objectives with the following priorities:

(1) Minimize the risk of endangering humans
(2) Minimize the chance of property damage
(3) Maximize the expectation of aircraft survival

Furthermore, additional constraints need to be satisfied: Ideally, the complete flight path should be within radio range, such that the chance of control link loss is minimized. According to current technical opinion an unmanned system can only be considered safe if the ground station operator is in full control. A control link loss means that the whole system is already in an unsafe operation mode. Moreover, the planned trajectory should be short and should preferably include only a limited number of course corrections. In addition, we want to plan a safe deployment position at low altitude in order to minimize the size of the expected landing area.

In order to find a suitable deployment position, we first extract relevant information from various map sources. Second, we model the chance of an accident based on the objectives described in Sec. 4 above. Third, we identify reachable parachute deployment positions with a low landing risk. Fourth, we select the best deployment position based on the landing risk, the risk of the approach flight path and additional constraints.

4.1 Risk Assessment

Modeling the probability of an accident occurring on the ground based on the landing position is a challenging task because only incomplete data is available. In order to estimate the expectation of human casualties, damages on the ground and air vehicle loss information from multiple map data sources is extracted. Primarily, publicly available maps, such as SRTM (Farr et al. (2007)) and OpenStreetMap (Haklay and Weber (2008)), are used as data sources.

The computed probabilities are stored as matrices, which divide the operational area into equally sized sectors. One element of the matrix $\mathbf{M}$ is represented as the vector $\mathbf{q} = (i, j)^T$, where i is the row and j is the column.

We model the risk $r(\mathbf{q})$ of the aircraft landing on the sector represented by $\mathbf{q}$ as

$$r(\mathbf{q}) = wp(\mathbf{q}) \quad , \tag{1}$$

where $p(\mathbf{q})$ is the probability of an accident occurring and w is the cost associated with the accident.

From OpenStreetMap we extract the set of all matrix elements $\mathcal{B} = \{\mathbf{q}_1, ..., \mathbf{q}_n\}$, covered by buildings. The expectation of human casualties is modeled in the following way: