Intelligent Contingency Management for Urban Air Mobility

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Abstract. The third aviation revolution is seeking to enable transportation where users have access to immediate and flexible air travel; the users dictate trip origin, destination and timing. One of the major components of this vision is urban air mobility (UAM) for the masses. UAM means a safe and efficient system for vehicles to move passengers and cargo within a city. In order to reach UAM's full market potential the vehicle will have to be autonomous. One of the primary challenges of autonomous flight is dealing with off-nominal events, both common and unforeseen; thus, intelligent contingency management (ICM) is one of the enabling technologies. In this context, the vehicle has to be aware of its internal state and external environment at all times, ascertain its capability and make decisions about mission completion or modification. All of these functions require data to model and assess the environment and then take actions based on these models. Necessarily, there is uncertainty associated with the data and the models generated from it. Since we are dealing with safety-critical systems, one of the main challenges of ICM is to generate sufficient data and to minimize its uncertainty to enable practical and safe decision making. We propose an overall architecture that incorporates deterministic and learning algorithms together to assess vehicle capabilities, project these into the future and make decisions on mission management level. A layered approach allows for mature parts and technologies to be integrated into early highly automated vehicles before the final state of autonomy is reached.

Keywords: Autonomy, contingency management, data-driven modeling, decision making.

1 Introduction to Urban Air Mobility

The third aviation revolution is seeking to enable transportation where users have access to immediate and flexible air travel; the users only need to dictate trip origin, destination, and timing. One of the major components of this vision is urban air mobility (UAM) for the masses. UAM means a safe and efficient system for vehicles to move passengers and cargo within a city. UAM is not a new concept; currently there are helicopter services within large metropolitan areas that shuttle a small set of users between predefined set of destinations. The paradigm shift in this new incarnation of UAM is the democratization of the service (Fig. 1) [1]. Thus, at its core, UAM refers to the aerial movement of people, cargo and information, from one point in an urban landscape to another. UAM has the potential to reduce emergency response time, aid in combatting congestion in dense, urban cores characterized by impasses (e.g., bridges and tunnels), and improve the comfort and speed of travel. The convergence of autonomous capability and adoption of electric vehicle technologies will likely set an industry standard and will enable these missions.

UAM also has the potential to enable a suite of advanced aerial mobility missions in the surrounding metropolitan areas, such as suburban and rural communities. As the technologies of UAM mature, the ability to facilitate intra-city transportation for short takeoff and landing applications, as well as operations such as package delivery for medical transport, will act to unlock opportunities for social and economic engagement in all areas of the nation.

The ability to access the airspace above urban areas for commercial opportunities via small unmanned aerial systems (UAS) under the FAA's Part 107 has created an industry that has been assessed to be worth $22 billion USD worldwide [2]. These assessed operations are mostly limited to surveying and surveillance applications, such as agricultural, infrastructure inspection, journalism, film making and law enforcement. Initial cargo-carrying operations, in rural areas, have just begun in the U.S., and are projected to become a dominant economic driver in urban and suburban areas. The UAS industry has also catalyzed interest in passenger-carrying UAM operations, which may be worth $15.2 billion USD by 2030 [3].

In this effort, we focus on a concept of operations that will involve passenger carrying UAM vehicles operating in an urban environment. We consider an intermediate state of operations, that is defined by 100s of simultaneous operations; expanded networks including high-capacity UAM ports; many available UAS Traffic Management [UTM]-inspired Aircraft Traffic Management services, simplified requirements for pilot certification; low-visibility operations.[4] Note that this vision requires that several key assumptions be made, specifically regarding the increasing level of autonomous operation exhibited by the vehicle as well as for UAM airspace management.

We assume the intermediate UAM mission to be comprised of a vehicle, that takes off from a pre-prepared landing site (e.g., a UAM port), and travels to another pre-prepared landing site. There is appropriate communications, navigation and surveillance infrastructure available to enable multiple simultaneous operations at a UAM port (and to enable 100s simultaneous operations in the urban airspace). The vehicle has some level of human supervision, be it remote or in the cockpit. However, the assumption of a highly trained pilot may no longer be valid, and the role of the human is that of an operator. The vehicle may encounter disturbances (e.g., weather events) and disruptions (e.g., restricted airspace or weather) in the course of its journey, and may have to deal with contingencies (e.g., faults and failures) in an increasingly autonomous fashion.

Fig. 1. Urban Air Mobility (UAM) notional mission for the masses.

There are several challenges posed by UAM operations and these challenges can be broadly separated into airspace-oriented challenges, vehicle-oriented challenges, community integration challenges and cross-cutting challenges. Airspace challenges include, but are not limited to, designing the airspace and operational procedures for UAM operations — including the design and operation of UAM ports and necessary supporting infrastructure, disruption due to air space restrictions, and fleet management, along with urban weather prediction. Vehicle challenges include safety, certification and noise qualities, as well as addressing issues such as increasing automation, manufacturing and supply chain issues, and maintenance. Community integration concerns are focused around public acceptance of the operations, their integration into a multi-modal transportation system and infrastructure (and the incorporation of smart cities technologies), as well as the local regulatory environment. Broad challenges such as safety, certification, autonomy and infrastructure required for UAM operations cut across all stakeholders in the UAM ecosystem and will require integrative solutions.

As these operations scale to the point where they will be profitable, it has been suggested that an increasingly autonomous operational paradigm will be required. [5, 6]. Moreover, in order to reach UAM's full market potential the vehicle will have to be autonomous. One of the primary challenges of autonomous flight, even at intermediate stage, is dealing with off-nominal events, both common and unforeseen; thus, intelligent contingency management (ICM) becomes one of the enabling technologies. Since we are dealing with safety-critical systems, one of the main challenges of ICM is to generate sufficient data and to minimize its uncertainty to enable practical and safe decision making. We propose an overall architecture that incorporates deterministic and learning algorithms together to assess vehicle capabilities, project these into the future and make decisions on mission management level. A layered approach allows for mature parts and technologies to be integrated into early highly automated vehicles before the final state of autonomy is reached.

2 Approach to Intelligent Contingency Management

We consider an architecture and associated functionality, see Fig. 2, that would allow the vehicle to safely achieve its mission by flying from pt. A to pt. B under all vehicle-allowable weather conditions, in a high-density airspace complex urban environment, and reacting appropriately to off-nominal situations and contingencies without direct human control. Currently contingency management is a highly prescribed, rule-based approach. We are interested in exploring intelligent contingency management that can appropriately handle unanticipated situations. This approach considers some emerging techniques in machine learning and explores their integration into safety-critical systems and associated levels of safety assurance. Some of the techniques under exploration are multi-agent reinforcement learning, variational autoencoders, and couple of flavors of neural networks. We are also investigating several assurance tools for both design and run-time implementation.

Fundamental to this architecture is a set of software components, each relying on a set of adaptive models, that maintain a two-way interaction between model and system measurements. At the highest level, these components maintain models of the vehicle:

- Present capability: based on dynamic physical vehicle models and models of vehicle safety
- Future state: based on reachability models and derivative data about present capability
- Mission execution: based on predictive vehicle flight models for decision making under uncertainty

Each component reflects the Dynamic Data Driven Application Systems paradigm, by using real-time data to enhance the vehicle’s function in a manner congruent to its real-world context.

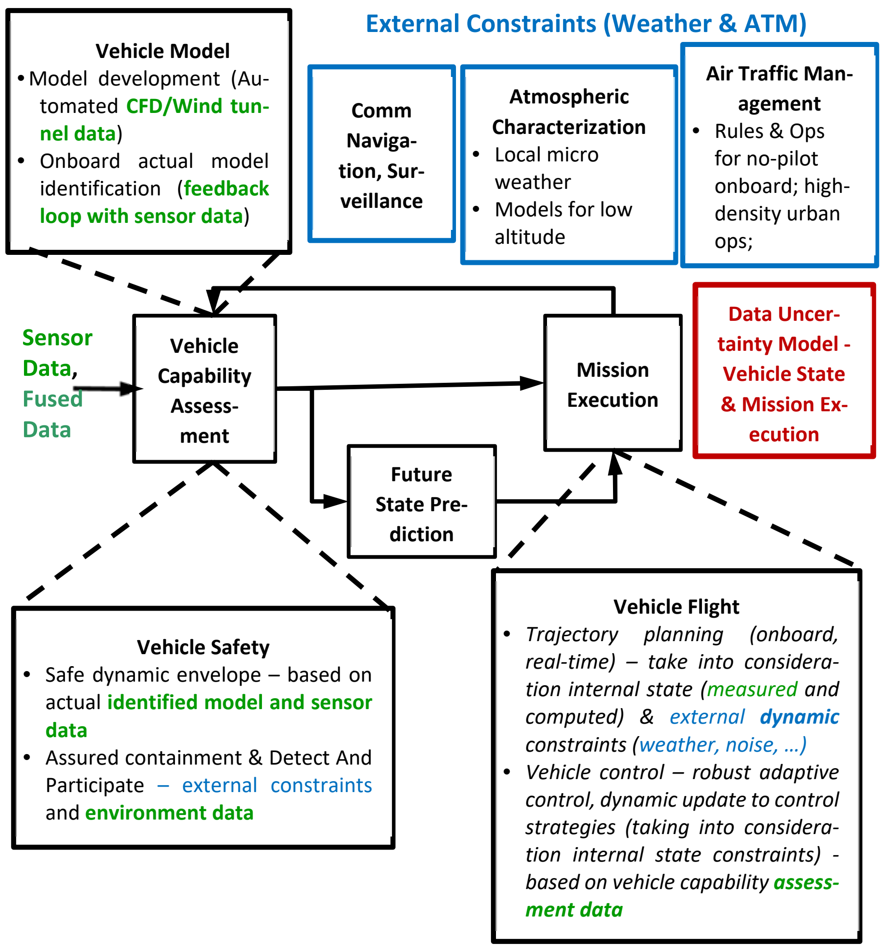

Fig. 2. Intelligent Contingency Management (ICM) architecture. The architecture provides examples of data from vehicle sensors (green) and from external sources (blue).

The collective state of the corresponding models for each component guide the incorporation of relevant data into the respective component during flight, as well as into the other system components. Furthermore, for computational feasibility, the level of fidelity for which data is analyzed and decision-making occurs is based on these models. Data flowing into a component improves the accuracy of its models and derivative analyses. Data flowing out to other components improve precision of predictions and control.

3 Summary

UAM is a large, emerging market with a goal of democratizing on-demand mobility. In order to reach UAM's full market potential the vehicle will have to be autonomous. One of the primary challenges of autonomous flight is dealing with off-nominal events, both common and unforeseen; thus, intelligent contingency management becomes one of the enabling technologies. Since we are dealing with safety-critical systems, one of the main challenges of ICM is to generate sufficient data and to minimize its uncertainty to enable practical and safe decision making. In this paper, we propose an overall architecture that incorporates deterministic and learning algorithms to assess vehicle capabilities, project these into the future and make decisions on mission management level. A layered approach allows for mature parts and technologies to be integrated into early highly automated vehicles before the final state of autonomy is reached.

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