

A method to implement and to evaluate a learning-based Piloting Autonomous System for UAS

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Abstract— The growing public interest for Unmanned Air Systems (UAS) applications has stimulated the debate over the integration of this kind of aircraft into the civil aviation system. However, the concept of not having a human pilot inside the aircraft presents uncertainties that may impede the creation of proper regulation. Having safety as the main concern for civil aviation, one important principle of aviation to be addressed in an UAS is collision avoidance, a traditionally pilot-dependent functionality. Therefore, we propose a method for implementing a learning-based Piloting Autonomous System. The proposed approach utilizes the concept of ‘Learning from Demonstration’ in order to define a behavior for the autonomous aircraft based on the maneuvers executed by a human pilot. By doing so, we expect the Piloting Autonomous System to be able to compensate for the lack of a human pilot in the aircraft. Therefore, the proposed approach would represent a possible implementation of an autonomous UAS that presents the same safety levels observed in (human-based) civil aviation. Additionally, we identify metrics that can be used to select a suitable learning-based method and to compare its performance to those observed in manned aircraft.

Keywords — UAS; collision avoidance; piloting autonomous systems; safety; sense and avoid

I. INTRODUCTION

The recent awareness of the possible applications for Unmanned Aerial Systems (UAS) has motivated the debate over how to integrate these aircraft into the Air Traffic Management (ATM) environment. As discussed in [1], such integration is a complex problem that involves interests from different stakeholders. From the viewpoint of Civil Aviation Authorities (CAA), safety is the main concern, even in spite of the growing commercial interest for UAS applications. However, for those regulatory authorities, the lack of knowledge on the topic still makes it difficult to define proper regulations. In this regard, the US Federal Aviation Administration (FAA) has been using test flights to better understand the inherent issues [2]. Therefore, it is possible to say that, due to the lack of knowledge on the subject, the integration of UAS into the ATM represents an important field for scientific research.

In this paper, we focus on an important safety issue of the UAS integration: collision avoidance, a traditional pilot-dependent functionality [2]. As discussed in [3] and [4], within a manned aircraft, one of the basic responsibilities of the pilot is to “see and avoid” other aircraft. Therefore, the

absence of a human pilot on the aircraft may represent the loss of a protection layer regarding collision avoidance, especially for autonomous flights.

As stated in [4], since the implementation of a human-equivalent “see” capability has been proving as a difficult challenge, an alternative would be to grant the UAS the capability of “sense and avoid”. As discussed in [3], the “sense” capability of a UAS relies mainly on identification data exchanges among cooperative aircraft.

Therefore, in order to compensate for the pilot removal from the aircraft in an autonomous UAS, we propose a method for implementing a Piloting Autonomous System (PAS), as proposed in [5], based on maneuvering demonstration provided by a human pilot. The PAS will be responsible for “sensing” obstacles (including other aircraft) and, by defining a behavior to the UAS that “mimics” a human pilot, we expect the aircraft to have autonomous capability to avoid such obstacles similarly to the one observed in human-piloted aircraft. Therefore, by keeping the same maneuvering capability when autonomously piloted, the UAS would not increase the Mid-Air Collision (MAC) risk, keeping the same safety level observed in manned aircraft in this aspect.

This paper is structured as follows: Section II presents a discussion over the current regulatory constraints for the use of autonomous UAS and some inherent issues. In Section III, we present an evaluation of the possible use of a learning-based method for the implementation of a PAS. Section IV proposes models of the airborne platform for the UAS and for the PAS. In Section V, we define metrics for evaluating the effectiveness of the proposed approach. Finally, in Section VI, we present the conclusions and future work.

II. REGULATORY CONSTRAINTS

In [6], ICAO (International Civil Aviation Organization) presents a snapshot of the regulatory framework under development for UAS and states that only a remotely piloted aircraft (RPA) “will be able to integrate into the international civil aviation system in the foreseeable future”. Therefore, it keeps the idea of having a “pilot in command”, responsible for the operation of the aircraft, as in conventional aviation.

However, as discussed in [5], the lack of scientific research regarding the safety of autonomous UAS constitutes one of the main reasons for such a limitation. Furthermore, it is important to address issues inherent to the RPA concept. One of those is the need of a wireless communication link between the ground station (where the pilot in command is

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located) and the aircraft. As reported in [7], conditions such as loss of the communication link is still a matter that requires research. In such a scenario, an UAS able to autonomously control itself could represent a possible mitigation measure.

Additionally, another important issue relates to human factors and ergonomics. As stated by [8], according to data presented in [9], UAS used in military applications of the US Department of Defense (DoD) presented a mishap rate about 50 times greater than the one observed in human operated military aircraft. Furthermore, in [8], the authors present the use of human factors standards and automation to improve the ergonomics of UAS ground station controls in order to reduce mishaps attributable to human factors. However, a UAS with autonomous control capability could represent another alternative in this regard.

III. LEARNING-BASED PILOTING AUTONOMOUS SYSTEM

In the following subsections, we discuss the adequacy of a learning-based method for the implementation of a PAS. Initially, we define the hypothesis adopted for the present work based on a safety policy adopted by several CAAs. Then, we present the learning-based method to be used in the PAS, with supporting evidence of feasibility from the literature. Finally, we present the reasoning that supports the use of a learning-based method in a safety-related application.

A. Safety Level

Having safety as a top priority in ATM, a number of CAAs have adopted the policy of requiring the UAS to meet equivalent levels of safety observed in manned aircraft [6]. As stated by [10],

“... an additional Unmanned Air Vehicle (UAV) operation must not increase collision risk to current civilian conventionally piloted aircraft (CCPA) more than an additional CCPA operating on similar routings would”.

Assuming that the lack of a human pilot on board of the UAV is the most significant factor to affect safety compared to a conventional aircraft, granting the UAV an autonomous piloting capability that “imitates” the human pilot would result in similar safety levels. That is the hypothesis adopted for this work.

B. Learn from Demonstration

In order to grant flight autonomy to UAS, we propose the use of the concept of “Learn from Demonstration” (LfD). In [11], the authors present a survey and categorization of the different techniques of LfD. Furthermore, [11] presents LfD as a subset of “Supervised Learning”, which consists in presenting a set of labeled training data to the agent, which will infer an approximation of the function that generated the training data. Specifically in LfD, the training data is obtained from example executions of the task performed by a “demonstration teacher”.

Based on the LfD concept, we will use the behavior observed for an aircraft when controlled by a human pilot (the demonstration teacher) as training data. Then, the UAS will be presented to those data in order to learn an approximation of the function (human pilot control) that produced those data (supervised learning).

In the literature (e.g. [12] and [13]), it is possible to find implementations of some learning-based control approaches, including one based on LfD [14]. Therefore, we consider the existence of several learning-based implementations as evidence of the feasibility of the approach proposed herein. In fact, the learning-based approaches presented in the literature represent suitable candidates for the control base of the PAS.

C. Learning Culture

As stated in [10], Air Traffic Control (ATC) systems are High Reliability Organizations (HRO), which have a learning culture as an intrinsic characteristic. In this sense, we consider the application of a learning-based approach to a UAS autonomous control is in accordance with ATC Systems interests. For training the UAS, it is possible to select a training data set obtained only from safe maneuvers. Hence, by excluding eventual erroneous unsafe maneuvers, the UAS would learn an approximation of a perfectly safe behavior. Ideally, an autonomous flight would present greater safety levels as compared to remote-piloted flights.

One possible source of training data could be the recordings of conventional aircraft surveillance data streamed from Radar systems. In [15], the authors utilized such data to construct statistical models of different kinds of aircraft. For the present work, those data could be adapted to generate a training data set that would be in accordance with conventional aircraft behavior.

Therefore, with a proper selection of the training data, we consider the proposed approach is capable of representing an enhancement to safety in UAS operations.

IV. UAV MODEL

This section describes the unmanned aircraft model proposed for the execution of proofs of concept and simulation. As the airborne platform, we will use a quadrotor helicopter assembled in accordance with the diagram of Fig. 1. Based on the formalization presented in [11], the LfD-based piloting control of the aircraft shall be capable of observing some states of the environment (“world”) and take actions accordingly. The following subsections describe the observation capabilities granted to the aircraft and the actions taken according to the process executed by the PAS.

A. Observed States

The proposed assembly makes it possible to observe the following states:

- Angles of rotation and angular speed in three dimensions (pitch, roll and yaw).
- Movement speed.

- Self-positioning.
- Obstacles locations.

It is important to notice that, according to the concept of “sense and avoid”, for the awareness of possible obstacles, our focus will be the implementation of cooperative communication through data link interface. Therefore, the autonomous control of the UAS will rely mainly on concepts such as ATC communication and Automatic Dependent Surveillance-Broadcast (ADS-B). However, as a real UAS application may have to consider non-cooperative conflicts as well (e.g. non-communicating aircraft), a camera is included in the aircraft model for possible machine vision experiments, although the implementation of such capability may require the use of concepts that are not in the scope of the present work.

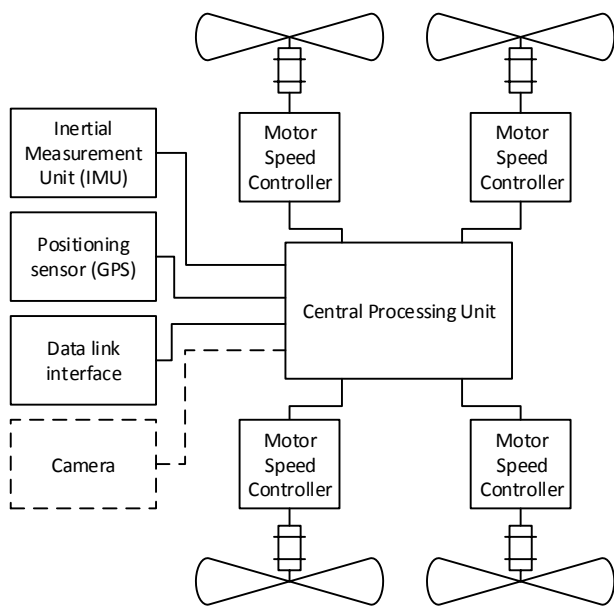


Fig. 1 Block diagram of the airborne platform assembly.

B. Piloting Autonomous System (PAS) Model

The Central Processing Unit within the aircraft will be responsible for the execution of the piloting control (Fig. 2). According to the observed states (sensor data and flight plan), the LfD-based PAS shall take actions, which correspond to defining values of set point for throttle, pitch, roll and yaw of the aircraft.

V. EVALUATION METRICS

As stated by [10], the collision risk assessment is the main element in the safety evaluation of a UAS operation. In order to evaluate the effectiveness of the LfD-based PAS for collision avoidance, we will use the approach presented in [15], which is based on the concept of Near Mid-Air Collision (NMAC). A NMAC is defined as being a loss of separation 100 ft vertically and 500 ft horizontally. Furthermore, the probability of a NMAC to lead to a MAC is assumed as 0.1. Hence, we expect the PAS to be capable of avoiding the occurrence of NMAC as much as a human pilot

is. With the collision risk criterion defined based on NMAC, it will be possible to execute a proof of concept for the proposed approach. That will be accomplished by making the LfD-based UAS execute flights in a shared airspace with cooperative obstacles (after the training process). According to the obstacles position informed through cooperative communication, the UAS shall demonstrate the capability of avoiding the occurrence of a NMAC. Therefore, the execution of this proof of concept is intended to (qualitatively) demonstrate the suitability of an LfD-based control method initially selected.

For the LfD-based methods selected according to the proof of concept tests, the next step will be the evaluation of the PAS in a simulation environment. In order to estimate the collision risk inherent to the introduction of the UAS in the civil aviation system, we will use the Monte Carlo simulation presented in [15]. Within this method, an encounter model shall be used to generate a large number of encounter scenarios, where the aircraft are in close range (yet not as close as in a NMAC condition). For each of those, the PAS will define a trajectory that possibly avoids the occurrence of a NMAC. The simulation results will represent an estimative of the collision rate due to the integration of the LfD-based UAS into the aviation system (quantitative analysis).

For each of the LfD-based control methods, we will compare the obtained collision rate to the ones observed by the introduction of similar manned aircraft and RPAS. We expect the collision rate of the LfD-based UAS to be similar to the other aircraft, which would represent an evidence of equivalent safety levels. Furthermore, eventual differences in the estimated collision rates presented by each selected LfD approach will have to be properly analyzed, in order to identify possible sources of discrepancies.

Ultimately, the proposed evaluation metrics represents a means to both selecting an LfD-based approach and to compare such approach to conventionally manned aircraft (regarding collision avoidance).

VI. CONCLUSION

In the following subsections, we present conclusions of the approach proposed herein and further activities for the effective implementation and evaluation of the method.

A. Proposed Approach

We presented an alternative for the implementation and evaluation of a Piloting Autonomous System for a UAS. Although the present regulation does not foresee the introduction of autonomous UAS into the civil aviation system, we presented plausible reasons for conducting academic research on the topic. Additionally, the existence of published literature supporting the concept of LfD adopted in the present work for the implementation of the PAS represents evidence of the feasibility of the proposed approach. Furthermore, we identified reasonable metrics to select suitable learning-based methods from within the LfD field and to evaluate a PAS in comparison to manned aircraft.

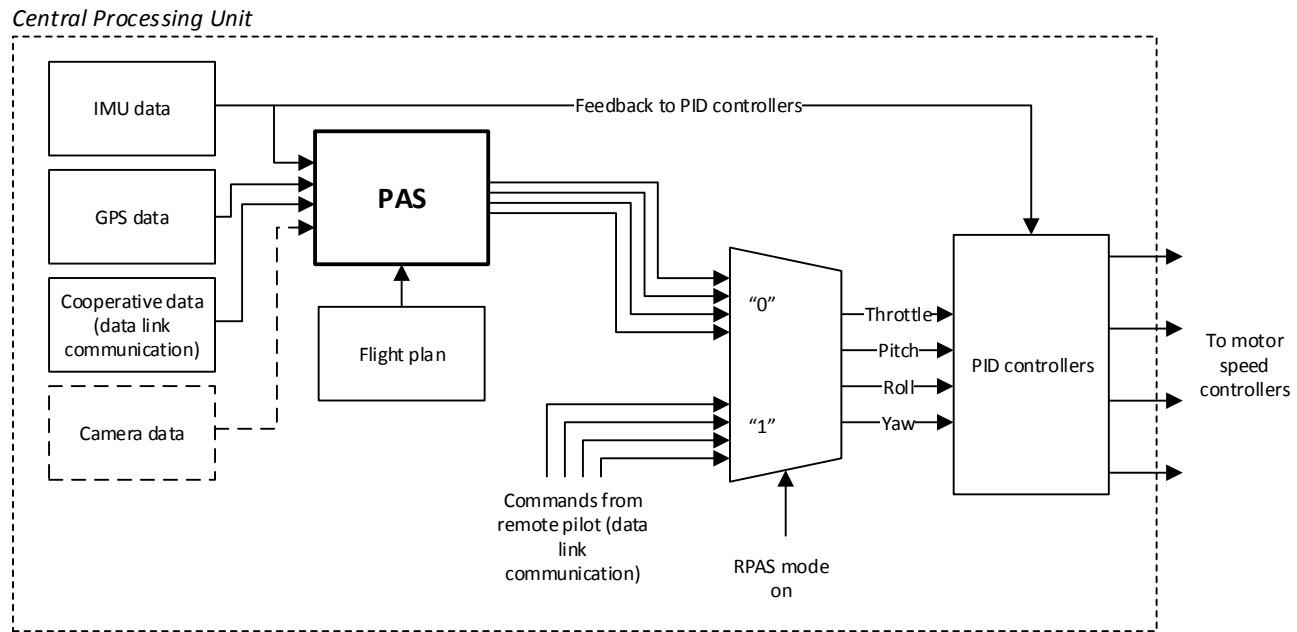


Fig. 2 Piloting control logic.

A. Future Work

The next steps for the work presented here consist of the proper implementation and validation of the learning-based approach as follows:

- 1) Proof of concept
 - a) UAV assembly
 - b) Selection of possible LfD approaches according to the literature
 - c) Piloting control (PAS and PID control) programming
 - d) PAS training
 - e) Verification of collision avoidance capability of the autonomous UAS (for each LfD selected approach)
- 2) Collision risk evaluation through PAS algorithm simulation.
 - a) Selection of a proper encounter model.
 - b) Adaptation of PAS to the simulation environment.
 - c) Evaluation of the results.
 - d) Definition of possible improvements.

REFERENCES

- [1] K. Ramalingam, R. Kalawsky, and C. Noonan, "Integration of Unmanned Aircraft System (UAS) in non-segregated airspace: A complex system of systems problem," in *2011 IEEE International Systems Conference*, 2011, pp. 448–455.
- [2] T. Hoffmann, "Eye in the Sky - Assuring the safe operation of Unmanned Aircraft Systems," *FAA Safety Briefing - May/June 2010*, no. June, pp. 20–23, 2010.
- [3] M. Contarino, "All weather collision avoidance for unmanned aircraft systems," in *Unmanned Systems Technology XII*, 2010, vol. 7692, pp. 1–9.
- [4] J. C. Moody and R. C. Strain, "Implementation Consideration for Automatic Dependent Surveillance-Broadcast on Unmanned Aircraft Systems," in *AIAA Infotech@Aerospace Conference*, 2009, pp. 1–8.
- [5] R. A. V. Gimenes, L. F. Vismari, V. F. Avelino, J. B. Camargo, J. R. Almeida, and P. S. Cugnasca, "Guidelines for the Integration of Autonomous UAS into the Global ATM," *J. Intell. Robot. Syst.*, vol. 74, no. 1–2, pp. 465–478, Sep. 2013.
- [6] International Civil Aviation Organization, "ICAO Cir 328, Unmanned Aircraft Systems (UAS)," 2011.
- [7] Federal Aviation Administration, "Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap," 2013.
- [8] Q. R. Waraich, T. a. Mazzuchi, S. Sarkani, and D. F. Rico, "Minimizing Human Factors Mishaps in Unmanned Aircraft Systems," *Ergon. Des. Q. Hum. Factors Appl.*, vol. 21, no. 1, pp. 25–32, Jan. 2013.
- [9] R. E. Weibel and R. J. Hansman, "Report No. ICAT-2005-1 Safety Considerations for Operation of Unmanned Aerial Vehicles in the National Airspace System," 2005. [Online]. Available: <http://dspace.mit.edu/bitstream/handle/1721.1/34912/Weibel-ICAT-Report-UAV-Safety.pdf>. [Accessed: 12-Feb-2014].
- [10] P. Brooker, "Introducing Unmanned Aircraft Systems into a High Reliability ATC System," *J. Navig.*, vol. 66, no. 05, pp. 719–735, Jun. 2013.
- [11] B. D. Argall, S. Chernova, M. Veloso, and B. Browning, "A survey of robot learning from demonstration," *Rob. Auton. Syst.*, vol. 57, no. 5, pp. 469–483, May 2009.

- [12] R. Hercus, H.-S. Kong, and K.-F. Ho, "Control of an unmanned aerial vehicle using a neuronal network," in *2013 IEEE Symposium on Computational Intelligence, Cognitive Algorithms, Mind, and Brain (CCMB)*, 2013, pp. 73–79.
- [13] F. Fernández, E. Besada, and D. Sanchez, "EXPERT GUIDANCE SYSTEM FOR UNMANNED AERIAL VEHICLES BASED ON ARTIFICIAL NEURAL NETWORKS," *J. Marit. Res.*, vol. 8, no. 1, pp. 49–64, 2011.
- [14] S. Ross, N. Melik-Barkhudarov, K. S. Shankar, A. Wendel, D. Dey, J. A. Bagnell, and M. Hebert, "Learning monocular reactive UAV control in cluttered natural environments," *2013 IEEE Int. Conf. Robot. Autom.*, pp. 1765–1772, May 2013.
- [15] M. J. Kochenderfer, M. W. M. Edwards, L. P. Espindle, J. K. Kuchar, and J. D. Griffith, "Airspace Encounter Models for Estimating Collision Risk," *J. Guid. Control. Dyn.*, vol. 33, no. 2, pp. 487–499, Mar. 2010.