The Autonomy Evolution in Unmanned Aerial Vehicle: Theory, Challenges and Techniques

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Abstract. The research areas in the field of UAVs have increased considerably during the last years, the research in this field is driven by the specific needs of each organization that conduct the research, There are two main research areas, the first is the operational and it is conducted by the governmental institutions and the universities, and the second is the technological and it is conducted mainly by the companies, This paper discusses the current technological research topics in the field of UAVs, focusing on the fuzzy-logic based methods which are employed in many control problems to increase the level of autonomy, the fuzzy-logic is considered as a promising hot subject which contains many active research topics and multiple potential tools for solving complex control problems to extend the UAV capabilities to perform different functions like Optimal path planning, Collision avoidance, Trajectory motion and path following autonomously without the need of the human pilot with the minimum human supervision, the paper illustrates the different levels, functions and challenges of autonomy and a comparative analysis is conducted to analyze four potential directions which are considered to be promising areas for fuzzy-logic based approaches. It also highlights the two main areas of AI research in the field of UAV autonomous flight, 1) the imitation of the human pilot and 2) the high-level applications like image evaluation, and how to tackle some of the problems in these areas with aid of fuzzy-logic based machine learning algorithms.

Keywords: UAV · Artificial Intelligence · Autonomous Flight · Fuzzy Logic

1 Introduction

UAVs are considered an essential part of the military industries and operations, adding that, it has a main role in many civil scientific and commercial purposes. Currently, UAVs are being developed to satisfy various needs and these needs are the main

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motive behind the growing UAVs research activities, many government institutions, universities, and research institutes, and public & private sector entities conduct research that fit their interests [1]. UAV research areas are divided into two main areas, the first is operational research area which focus on effective usage in terms of policies, certifications… etc. The second research area are technological, the private sector is active in this area and universities and research institutes take part in some research activities, the two areas affect one another and they are interconnected, e.g. the level of autonomy determines the type of missions that could be achieved by a UAV, generally speaking, both domains focus on making the most of the UAV [2].

For the human societies, autonomy is the ability for an individual to make an informed, self-made decision with his own rules and to be goal directed in a constantly changing environment. Autonomy for the machine is to be able to do a collection of functions such as, sensing, perceiving, analyzing, communicating, planning and decision making without human intervention and to be goal directed in unpredictable situations which may vary greatly from low to high altitudes in a crowded airspace. The theory behind autonomous flight borrows from many disciplines such as, aeronautical engineering, automatic control, artificial intelligence and other disciplines [3]. It provides a control architecture that merges algorithms for mission planning, trajectory generation, path following and adaptive control theory meeting strict performance requirements such as all maneuvers have to be collision free [4]. Table 1 below expresses the ten levels of automation Table 2.

Table 1. Automation Levels

Level	Description
1	No computer assistance; the operator must make all decisions and take actions
2	System provides a wide-ranging set of decision/action
3	System narrows the selection down to a few
4	System provides an alternative
5	System executes a suggestion after the operator approval
6	System allows the operator a limited time to veto before the execution
7	System executes automatically, then informs operators
8	System informs the operator only if asked
9	System informs the operator only if it decides to
10	System decides whole actions and acts autonomously, ignoring the operator

Table 2. Functions (Research Areas) of the Unmanned Aerial Vehicles

Number	Research Area
1	Sensor and other information fusion
2	Communication management
3	Optimal path planning
4	Collision avoidance
5	Trajectory motion and path following
6	Target identification and threat evaluation
7	Abort decision-making/ response
8	Task scheduling

UAVs are classified mainly to two types as is the case in any aircraft, 1) Fixed wing and 2) Rotorcraft, with different theory of operation, flight dynamics, control system and different applications, this paper focuses on the potential techniques of increasing the automation level through using a suitable control architecture for both types. UAVs are classified to be able to have a common terminology as a reference to enhance communication between different parties taking into consideration that each entity has its own categories [5]. Figure 1 below represents the main difference between fixed wing & rotary wing, while Fig. 2 shows the basic fixed wing aircraft components.

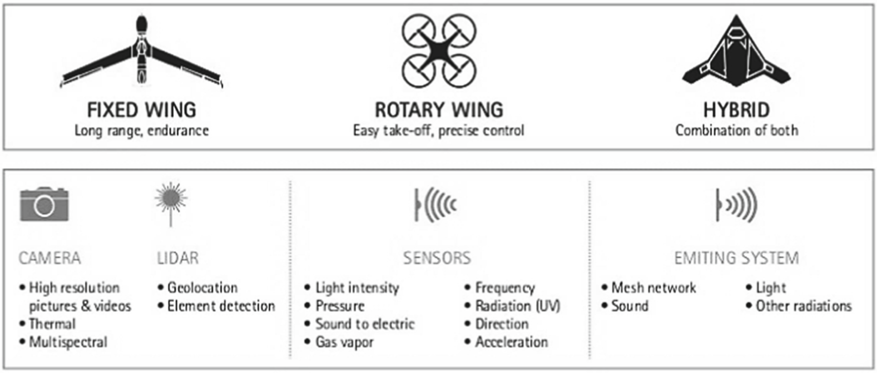

Fig. 1. An illustration between various types of UAVs

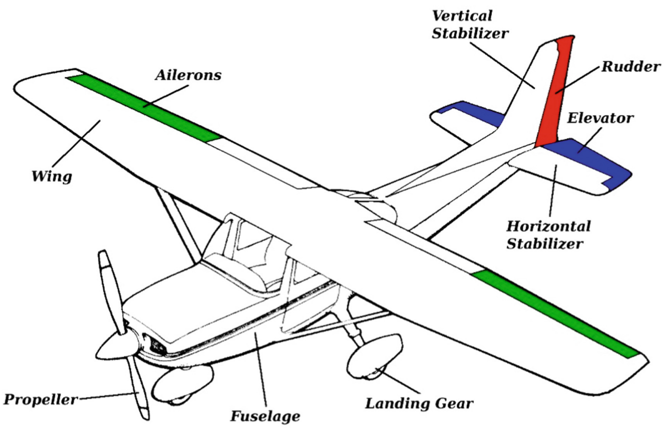

Fig. 2. Sketch illustrates the main components of the ordinary aircraft

This paper is organized as following, Sect. 2 is a literature review of previous studies related to automation enhancement in UAV through different techniques, while Sect. 3 discusses the main challenges that face automation in UAVs, Sect. 4 shows fuzzy-logic role in enhancing UAV automation level, finally Sect. 5 is a summarization for the overall discussed ideas in the paper.

2 Literature Review

During the past, there has been extensive research work by control experts and scientists on developing a powerful fault-tolerant control system for different aircraft, that could sustain a steady flight in adverse conditions. This paper main objective is to demonstrate fuzzy-logic based autonomous navigation and control main topics and analyze the major work in these fields. In this section, we are going to present four papers that used artificial intelligence approaches to improve the autonomous control level with different control strategies for UAVs [6].

(C. Sabo et al., 2012) There are many cases in which Unmanned Aerial Vehicles are subject to obstacles while maneuvering in an environment especially when having little prior understanding of the surrounding objects. To be able to move towards any target in unknown conditions and the environment in real-time, we should provide an algorithm that could conduct dynamic motion and path planning. This paper focuses on developing a fuzzy-logic based approach for two-dimensional motion planning, this fuzzy system take gathered information about the obstacles with the aid of sensing devices and target location and it modifies the heading angle and the speed. The performance of the fuzzy-logic controller was evaluated by validation and testing methods like Monte Carlo. The fuzzy-logic controller enables the UAV to follow the exact path provided by the optimal path algorithm with a very low failure rate which shows the potentiality of further exploration of such controllers. The fuzzy-logic control method with about a 3% failure rate, versus a common intelligent control method called Artificial Potential Field (APF) of about 18% failure rate, illustrates the benefits of such a system of adaptability to complex situations with minimum effort [7].

(M Norton et al., 2014) have proposed in their study an adaptive fuzzy multi-surface sliding control (AFMSSC) for trajectory tracking of 6 degrees of freedom for aerial vehicles with multiple inputs and multiple outputs (MIMO). They have explained that the adaptive fuzzy logic-based function approximator could be the main tool to have an estimation for the system uncertain aspects of the system and the flight could be controlled with an iterative multi-surface sliding control. Using AFMSSC with MIMO autonomous flight systems could provide a type of control that could serve matched and mismatched uncertain aspects, internal dynamic excitation and disturbances of the system. The AFMSSC system has assured the output tracking and the boundedness of the tracking error. Also, they also presented the results of the simulation to validate their analysis [8].

(N Ernest et al., 2016) The authors of this paper introduce ALPHA, an Artificial Intelligence that controls Unmanned Combat Aerial Vehicles in virtual combat with a high precision simulation environment. They have utilized the fuzzy logic-based Artificial Intelligence approaches that could be used to solve highly complex control problems. This problem represents one of the most complex applications of a fuzzy-logic based Artificial Intelligence to an Unmanned Combat Aerial Vehicle control problem. This advancement has been possible by the progress in genetic fuzzy tree methodology. The ability to have higher performance, increased computational efficiency, besides robustness with uncertainties, adaptability with changing situations, verified and validated that it follows the safety specifications and operating instructions with definite practices, the easiness of the design and execution are some of the strength points of this type of control [9].

(M Talha, 2018) This paper proposes a fuzz logic-based position and speed control auto landing technique. This system controls the attitude of the UAV system by the usage of velocity information and real-time position. The proposed fuzzy logic controller which can be considered as a hybrid of position and velocity control algorithm provides a fast and autonomous landing performance. Controlling the velocity is responsible for secure landing and it protect the UAV from hitting the ground at high speeds. Position control is important to determine the altitude and to generate commands that overcame the in-ground-effect for easy and fast landing. This fusion between position and speed control improve the efficiency because it reduces the landing time and raises the safety emphasis comparing to conventional controllers [10]. The response time during landing could be enhanced by the adoption of Lookup table-based fuzzy logic technique which improved the execution time as compared to a normal fuzzy technique. With the aid of the simulation environment we could compare the conventional PID controller to the landing controller proposed, the results have illustrated clear refinement to the previous method. Moreover, this technique has been applied to a quadcopter to verify its capability in the real world, the results are used to verify the practical utilization in real-time. It could be noticed that the proposed controller is safer and quicker when comparing to conventional methods. This technique could be applied for all types of copters without significant modifications [11].

3 Autonomous Unmanned Aerial Vehicles Challenges

Autonomy of a UAV is affected by many factors including environmental difficulty, mission complexity and the level of human intervention to achieve the mission goals. The main objective of UAV regulations is to maintain safe operations quantified as an equivalent level of safety with the manned aircraft. The level of the UAV autonomy will pose some certification issues such as: The compliance of human-machine interaction with the current air traffic control (ATC) instructions, handling UAV failures, collision avoidance and avoidance of sensitive areas and objects. Aircraft sense and avoid systems (SAA) focus on ensuring adequate level of safety by executing self-separation and collision avoidance [12].

Small UAVs face a difficult regulation challenge, with thousands of them are sold yearly, a beginner could build a small UAV easily with available parts with many resources and parts are sold locally or from the internet. UAVs can pose a real threat to many aerial vehicles including commercial aircraft, and other ground facilities.

The control could be lost between the operators and the UAV during flight. It has been reported that UAVs have been used in many illegal conducts like contraband smuggling for prisoners and across borders, but there has been no serious accident. Regarding the security and privacy aspect, the risks posed by the improper usage of UAVs represent a risk to people's privacy, with its high altitude and camera recording capabilities it could be used to make video recordings for people's properties through many ways. So, this aspect hasn't reached the required level for minimal risk. These challenges have been addressed by the governmental bodies with multiple strategies, the ownership and operations for UAVs are regulated the law enforcement agencies ensure that rules are applied supported by many technological tools that could start from signal jamming and end with capturing and attacking to bring down the UAV [13].

3.1 Artificial Intelligence

AI Application in the UAVs can be divided into two main areas:

- **First Area:** Imitation of the human pilot behavior by the machine in different scenarios to maintain the controllability and stability of the aircraft different systems and ensures that the aircraft achieves its objectives, common examples are object detection and obstacle avoidance. Currently, many flying aids support the human pilot in many tasks. There is ongoing work to introduce the UAVs to the civil airspace. The current operations of the UAVs depend heavily on human pilots, the Artificial Intelligence methods are powerful tools to increase the level of independence and can contribute for a smarter UAVs that could operate without even the need of human supervision [14]. There are many challenges to be explored in this area. The current operations of the UAVs depend heavily on human pilots, the Artificial Intelligence methods are powerful tools to increase the level of independence and can contribute for a smarter UAVs that could operate without even the need of human supervision. There are many challenges to be explored in this area.
- **Second Area:** Image/data evaluation; many technologies are assured such as "Auto image recognition", a common example for this technology is "Nametag assignment" for taken photographs, the current technologies for examining media file especially videos and photos are usually expensive and time-consuming, the usage of an image recognition technology with a suitable applied AI approach would make it easy for the AI to simplify the identification process for the person in the loop for further assessing and decision making [15].

AI and software systems are required to gather the sensor information and make proper decisions. To make sure that these systems could achieve their objectives in highly uncertain situations, extensive simulations are performed to assure the behavior of these autonomous systems. These technologies also should be designed and tested to verify their level of safety, also, AI systems should be trained by simulation models of different dynamic environments, airspace, and adverse weather [16]. By using different tailored simulations, the development of optimized, safe and reliable systems could be faster for testing and certifying than using physical models. The potential of AI applications in UAVs is huge that with just some flying hours connected with the internet, the UAV can use a camera to take pictures, process them and increase the intelligence level [17]. This will make it able to refine the software to be better in achieving the assigned objectives. While doing some tests, the AI-powered UAVs proved to be able to explore various environments without interventions by just trial and error method. UAVs could use the data gathered from the sensors and analyze the obstacles to help it plan its way. 'Fuzzy Logic' is one of the main Artificial Intelligence approaches applied for this purpose. UAV is used in industry in many various sectors (i.e. Mining, Telecommunication, Insurance, Media, Security, Transport and Infrastructure) [18] as shown in Fig. 3 below.

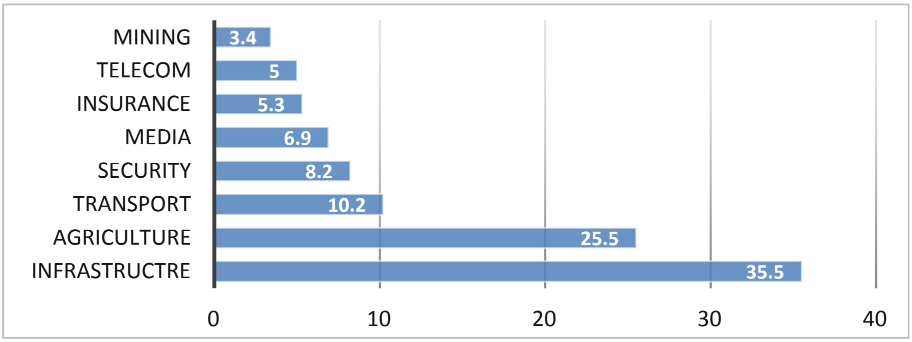

Fig. 3. UAV usage rate by various industry sectors (Commercial Drone Professional, 2018)

4 Fuzzy-Logic Role in Increasing UAV Autonomy Level

Fuzzy logic is a practice of multiple-valued logics where true values can be a real number between zero and one. It is main function is to represent the definition of partial truth, where the true value can be set between entirely true and entirely false. The main target of this section is highlighting four previous studies that discussed the autonomous improvements in UAV through fuzzy logic; to enhance its control systems [19]. In Table 1, a comparative study on four papers were made; to clarify different fuzzy logic techniques for solving various autonomy UAV challenges Table 3.

As future work, the usage of MATLAB/Simulink based UAV simulation system can be used as a comparative study on the previously discussed four papers with various parameters [20]; in order to measure the improvement autonomy level in each experiment, the simulation sketch of the application is shown in Fig. 4 above.

Table 3. A comparative study between four researches related to fuzzy-logic & artificial intelligence applications in autonomous flight

Paper No.	Challenge	Technique	Goal
(C. Sabo et al., 2012)	Maneuvering and moving towards any target for unknown environment conditions in real-time	A fuzzy-logic based approach for two-dimensional motion planning	An algorithm that could conduct dynamic motion and path planning
(M Norton et al., 2014)	Provide a type of control that could serve matched and mismatched uncertain aspects, internal dynamic excitation and disturbances of the system	An adaptive fuzzy multi-surface sliding control (AFMSSC) for trajectory tracking of 6 degrees of freedom for UAV with multiple inputs and multiple outputs (MIMO)	To have an analyzed and validated AFMSSC system for output tracking and the boundedness of the tracking error
(N Ernest et al., 2016)	To have higher performance, increased computational efficiency, besides robustness with uncertainties, adaptability with changing situations	ALPHA, an Artificial Intelligence that controls Unmanned Combat Aerial Vehicles in virtual combat with a high precision simulation environment	To solve highly complex control problems using a fuzzy logic-based Artificial Intelligence approach
(M Talha et al., 2018)	Reducing the landing time without compromising the safety emphasis	A fuzzy logic-based position and speed control auto-landing technique	Controlling the UAV attitude system by the usage of velocity information and real-time position

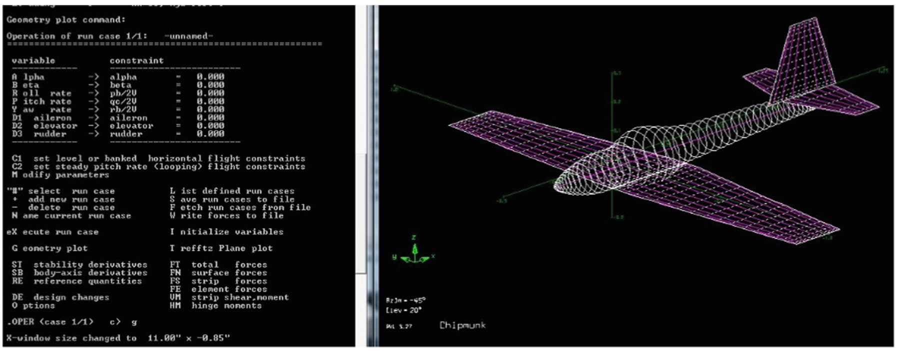

Fig. 4. An example of MATLAB/Simulink usage-based UAV simulation system

5 Conclusion

This paper has discussed the current challenges in using fuzzy-logic control in increasing the level of autonomy for UAV complex control problems, the papers discussed introduced the fuzzy-logic based ordinary and machine learning algorithms approach that could solve the complex-control problems. For I) general control problems, 1) it is proved that the AFMSSC system guarantees asymptotic output tracking and ultimate uniform boundedness of the tracking error. Simulation results are presented to validate the analysis. 2) An algorithm that could conduct dynamic motion and path planning. A fuzzy-logic based approach for two-dimensional motion planning. II) And in more Specific Applications, 3) ALPHA, an Artificial Intelligence that controls Unmanned Combat Aerial Vehicles in virtual combat with a high precision simulation environment. to solve highly complex control problems using a fuzzy logic-based Artificial Intelligence approach, to have higher performance, increased computational efficiency, besides robustness with uncertainties, adaptability with changing situations. 4) Reducing the landing time without compromising the safety emphasis. Controlling the UAV attitude system by the usage of velocity information and real-time position. A fuzzy logic-based position and speed control auto-landing technique. This work adds immensely to the body of evidence that this methodology is an ideal solution to a very wide range of control problems. And it could serve as a robust control system in the adverse conditions and uncertainties of the surrounding environments.

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