<center>**Autonomous Flight Control Systems for Drones**</center>

**Introduction**

Quadcopter drones require elaborate flight controllers to maintain proper roll, pitch, yaw and throttle. Adding autonomy to these basal requirements for a flight control system introduces legal and technical challenges. This technical review summarizes the state-of-the-art in autonomous drones used for personal, commercial and research purposes and discusses the legal implications of autonomous flight control systems.

**Personal Applications of Autonomous Flight Control**

Anyone who has ever flown a cheap drone has had the experience of watching the contraption zoom into nearby walls or bodies of water. Some of these cheap drones are even equipped with cameras intended for capturing aerial photography but due to lack of stability under manual control their use in such applications is limited. Companies such as DJI have sought to solve this problem using autonomous flight control systems in higher-end commercially available products. Their Mavic Air drone includes autonomous features such as return to home, collision avoidance, and various intelligent flight modes [4]. A few intelligent flight modes deserve special attention:

*ActiveTrack*

The ActiveTrack mode allows the drone to track a moving object. The mode allows for a few different forms of object tracking: from the back at constant distance, from the side at constant angle and distance, and a spotlight mode which keeps the camera pointed at the object without disabling manual control [4].

*SmartCapture*

DJI has developed the ability to recognize simple hand gestures using deep learning. The drone can be instructed to elevate or lower itself, distance itself, and even autonomously follow a subject [4].

**Commercial Applications of Autonomous Flight Control**

Drones have found use in various commercial capacities. Two particularly interesting applications are their use in agriculture and delivery services.

*Agriculture*

Due to the sheer amount of land requiring monitoring on a typical farm, myriads of field hands are required to ensure proper growth of crops. Drones reduce the quantity of employees a typical farm needs and increase yield by monitoring soil and irrigation conditions. The drone is able to cover large distances capturing and analyzing photographic data without disturbing the crops and can even administer pesticide and identify areas where attention is required [5]. Under the close scrutiny of drones, farmers

can focus more on the areas of a farm performing suboptimally rather than examining the whole field. The reduction in field hands also reduces the cost of produce to the consumer.

*Delivery*

Amazon, the world's largest e-commerce site, is in the process of developing the world's first to-home air delivery system. The delivery system will use drones to deliver small packages in under 30 minutes to those living near distribution centers. With Amazon Prime's offer of two-day delivery on most items being a driving factor in purchasing decisions, Amazon recognizes the competitive advantage autonomous drone delivery presents.

**Research on Autonomous Flight Control**

To enable autonomous flight, control systems are typically composed of various sensors such as attitude, airspeed, gps, barometer, and LiDAR distance sensors [8]. Typically the output of these sensors is examined by a microcontroller which in turn makes decisions based on the given data [8]. The microcontroller is given some overall directive by a non-observant pilot and expected to make the correct decisions to reach the objective. The autonomous flight control system has complete control over the speed of all propellers and other outputs of the system. For applications like flight, the microcontroller chosen as the brains of the operation must be capable of high speed calculations to enable real-time control of the aircraft [8]. The sensors chosen for the system must also be accurate and precise enough to be used in flight applications. Bad sensors can cause unstable flight dynamics and for this reason backup mission-critical sensors, such as the IMU, are typically included.

**Legal Challenges to Autonomous Flight Control Systems**

It is no secret that in recent years regulations surrounding both commercial and personal use of drones have become much more strict. This is brought about in part due to greater access to drones. Drones are cheaper than ever before and pose a threat to public safety and protected airspace. Despite how light drones must be in order to fly, the DJI Mavic Air is only 430g for instance, they present a risk for bodily harm [1]. Drones are equipped with quickly moving sharp propellers and those used for racing can reach speeds up to 120mph [3]. To establish a definite liability for any drone operator involved in an accident, the FAA requires that recreational flyers register and mark their drone and keep it within visual line of sight [7]. The FAA allows public safety and government organizations to self-certify UAVs but still requires visual line-of-sight operations only [6]. This draws into question the legality of non-observed autonomous flight. Identification of a liable party for accidents occurring when the UAV is operating autonomously is likely a reason for this. Luckily for public safety applications, the FAA has defined a

clear agenda to identify ways in which UAVs can be used to enhance the effectiveness of local law enforcement and first responders under section 366 in the FAA Reauthorization Act of 2018 [2].

[1] "DJI Mavic Air - Specs, Tutorials & Guides - DJI," DJI Official. [Online]. Available: https://www.dji.com/mavic-air/info#downloads. [Accessed: 26-Feb-2020].

[2] H.R. 302. 2018, p.125.

[3] "Learn More - Beyond the Basics of FPV Drone Racing," The Drone Racing League. [Online]. Available: https://thedroneracingleague.com/learn-more/. [Accessed: 26-Feb-2020].

[4] "Mavic Air: User Manual," Mavic Air: User Manual. DJI, Shenzhen.

[5] M. Mazur, "Six Ways Drones Are Revolutionizing Agriculture," MIT Technology Review, 22-Jul-2016. [Online]. Available: https://www.technologyreview.com/s/601935/six-ways-drones-are-revolutionizing-agriculture/. [Accessed: 26-Feb-2020].

[6] "Operate a Drone, Start a Drone Program," FAA seal, 14-Feb-2019. [Online]. Available: https://www.faa.gov/uas/public_safety_gov/drone_program/. [Accessed: 26-Feb-2020].

[7] "Recreational Flyers & Modeler Community-Based Organizations," FAA seal, 18-Feb-2020. [Online]. Available: https://www.faa.gov/uas/recreational_fliers/. [Accessed: 26-Feb-2020].

[8] S. Wang, Z. Zhen, F. Zheng and X. Wang, "Design of autonomous flight control system for small-scale UAV," Proceedings of 2014 IEEE Chinese Guidance, Navigation and Control Conference, Yantai, 2014, pp. 1885-1888. [4] "Recreational Flyers & Modeler Community-Based Organizations," FAA seal, 18-Feb-2020. [Online]. Available: https://www.faa.gov/uas/recreational_fliers/. [Accessed: 26-Feb-2020].