Real-Time Collision and Obstacle Avoidance in Unmanned Aerial Systems

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The impending entrance of unmanned aerial systems (UAS) into national airspace has sparked a large amount of interest into the problem of collision and obstacle avoidance in autonomous aircraft operations. The UAS must be compliant with various sections of Federal Aviation Administration Title 14 of the Code of Federal Regulations. Most notably, the lack of an on-board pilot mandates the "see-and-avoid" provisions of 14 CFR 91.113, *Right-of-Way Rules*. Domestic use of UAS could include operations in urban settings where fixed obstacles (e.g. buildings, trees, etc.) pose safety concerns. The notion of autonomous UAS sharing runways and airways with manned commercial or general aviation aircraft also illuminates a need for robust collision avoidance systems (i.e. "see-detect-avoid") and advancement in air traffic management procedures. UAS will require the capability to generate collision and obstacle free trajectories and execute tight tracking in real-time for safe operations to be ensured. In short, guidance and control for collision and obstacle avoidance in multiple aircraft, whether coordinated or not, must be generated with computational efficiency and executed with high fidelity. In this work, online trajectory generation is achieved using a novel approach to artificial potential field navigation methods. Further, the approach is tailored for integration with nonlinear guidance logic and nonlinear model predictive control (NMPC), where real-time dynamic trajectory information is forecast in a predictive horizon and embedded into an augmented model of the aircraft. The combined techniques are examined in full nonlinear six-degree-of-freedom (6DOF) simulation with a rigid body description of a large UAS which is called the Meridian (Fig. 1).

Figure 1: UAS Collision and Obstacle Avoidance in a Dynamic Environment

Navigation in evolving environments is achieved by applying repulsive and attractive potentials to obstacles and goals, respectively, and commanding the agent to follow the negative gradient of the summed potential field. The low complexity and decentralized nature of the approach makes it the candidate of choice. As the NMPC is a numerical control technique, the aircraft physics-based model is discretized. The Euler method is used in this work to avoid complexity and computational costs of higher order methods. Further, the model is augmented by embedding guidance and trajectory information composed as straight segments between consecutive waypoints. Two new outputs to the system are defined as angular errors (in the lateral and longitudinal planes), formulated from the current trajectory segment data and guidance logic. The task of the NMPC will be to indirectly minimize attitude errors within the prediction horizon, generating a robust, feasible control sequence while adhering to state output and control input constraints and keeping a tight trajectory following. To improve the resilient of controller in unstructured environment, the NMPC calculations have been done with an addition of robustness. By the use of loop shaping, the NMPC is successfully adapted to provide a level of robustness facing external disturbances, including measurement noise, and internal disturbances as bounded uncertainties. The loop shaping approach was mainly used to effectively reduce the bandwidth of the control solutions and of the whole closed loop, for more realistic results.