AIR-TRAFFIC MANAGEMENT AND CONTROL
OF
MANNED AND UNMANNED AIRCRAFT
IN
THE NATIONAL AIRSPACE
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ABSTRACT

The availability of small, low cost, reliable Inertial Navigation System (INS), and Global Positioning System (GPS) sensors, along with new powerful, inexpensive microcontrollers are providing new sophisticated auto-pilot systems for a rapidly growing array of unmanned aerial vehicles (UAVs). Keeping these UAVs separated from one another and from manned aircraft operating in the national air-space is a daunting challenge for which there is not yet have a suitable solution. At present, manned aircraft separation is maintained (most of the time) by a system of airspace classification and flight rules and by the Federal Aviation Administration (FAA) flight control centers. The enroute traffic over the lower 48 states is controlled by the 20 Air Route Traffic Control Centers (ARTCC) that rely primarily on long-range radar to keep track of the aircraft. Aircraft being so controlled are equipped with transponders that broadcast an identification signal (and sometimes their altitude) when they sense that the ATC radar signal is present. The radar receiver gets both the reflected signal from the aircraft and the transmitted identification signal and is able thereby to know both the location and identification of each aircraft. Around airports they use visual observations from Aerodrome Control Towers (TWR) or shorter range and more accurate radar in Terminal Radar Approach Control (TRACON) centers. Controllers in these centers maintain communication with pilots through the use of UHF/VHF radio channels.

The NextGen ATC modernization and improvement plan calls for replacing the radar data used by ATC with data transmitted by each aircraft on the Automatic Dependent Surveillance-Broadcast (ADS-B) radio channels. ADS-B data is taken from the GPS system of the aircraft and is more accurate and provides more information than the radar system. Furthermore, the ADS-B signal transmitted from one aircraft can be monitored by other aircraft giving pilots the location of other aircraft without relying on receiving that information from ACT. The NextGen plans calls for aircraft to broadcast their position and velocity information and at some future date to also broadcast their "intent" though the FAA has not described how the intent information is to be expressed or used. The application of the air traffic control system to the management and control of unmanned aircraft has not been defined. This paper describes a method for defining the flight paths of aircraft, both manned and unmanned, that provides a basis for a new kind of auto-pilot that gives improved control of the individual aircraft in flying the complex paths envisioned by the NextGen system and provides a means of defining and sharing flight "intent". It further provides means of autonomously detecting impending incursions (aircraft getting too close) and autonomously modifying the flight path(s) to mitigate the impending incursion(s).

Segmented polynomial functions provide a smooth analytical model of a flight trajectory along a sequence of waypoints. The trajectory model includes not only the geographic flight path but also the velocity, acceleration, and time along the path. A waypoint consists of a geographic position (longitude, latitude, and altitude), the velocity vector, the acceleration vector and time of the trajectory at that position. The coefficients of the segments of the polynomial functions are selected so that the flight path passes through the waypoints, matching the velocities, accelerations and times. Since the entire trajectory model is captured by a sequence of waypoints, or alternatively by a sequence of polynomial coefficients, a complete flight plan (intent) may be simply and unambiguously communicated in a compact uniform data set. If an aircraft is controlled to fly along the trajectory (including velocity, acceleration and time control) anyone (an air traffic controller or another aircraft in the same air space) having the flight model data set could compute the position, velocity, and acceleration for the aircraft at all instants during the flight. Anyone having the flight model data sets for two or more aircraft could readily compute the parameters (times, locations, etc.) of the minimum separation between the aircraft.

The trajectory model includes analytical expressions for the curvature and torsion of the flight path. These can be used to compute the control requirements for coordinated (non-side-slipping) turns (in terms of attitude and attitude rate) and with the addition of air-data measurements the control conditions for coordinated flight in the presence of wind.
The paper presents the details of the mathematical model and illustrates its application for flight planning, navigation, traffic management, collision avoidance, and coordinated control for complex turns. The model is applicable to and simplifies all phases of flight from take-off, through pattern departure, cruise, merging into arrival traffic patterns, to landings. The trajectory model data-set can be readily and automatically altered in flight to implement dynamic real-time navigation to accommodate collision avoidance, weather avoidance, changes in destination, or any other local or global alteration of the flight plan.