C-20A/GIII Precision Autopilot Development
In Support of NASA’s UAVSAR Program

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Abstract - The NASA Unmanned Aerial Vehicle Synthetic Aperture Radar (UAVSAR) program is developing a Synthetic Aperture Radar (SAR) for ground measurements. A key element for the success of this program is a Platform Precision Autopilot (PPA). An interim vehicle (NASA C-20A/GIII) was selected to carry the radar pod and develop the PPA. The PPA interfaces with the C-20A/GIII aircraft by imitating the output of an Instrument Landing System (ILS) approach. This technique retains the safeguards in the aircraft’s autopilot. The PPA entered initial flight testing in early 2007.

The PPA uses a Kalman filter to generate a real-time position solution with information from the C-20A/GIII and a real-time differential GPS unit designed by NASA’s Jet Propulsion Laboratory (JPL). The real-time navigation solution is used to compute commands (Guidance and Control subsystems) which in turn drive two modified ILS testers. The ILS tester units produce modulated RF signals fed to the onboard navigation receiver. These correction signals allow the C-20A/GIII autopilot to fly a simulated ILS approach that meets the PPA requirements for UAVSAR applications. The PPA requirement is to make repeat pass flights within a ten meter tube over a 200 kilometer course in conditions of calm to light turbulence.

This paper will address the development of the precision autopilot (PPA) to meet system requirements, its architecture, and demonstrated performance in testing.

I. INTRODUCTION

The earth science community has a need for earth deformation measurements at a variety of temporal scales, from seconds to decades. The NASA-JPL Unmanned Aerial Vehicle Synthetic Aperture Radar (UAVSAR) and Platform Precision Autopilot (PPA) are current enabling technologies to allow repeated mapping of Earth surface deformations with an interval on the order of minutes [1]. The UAVSAR will have the capability to conduct radar repeat pass interferometry measurements of surface deformation to millimeter level accuracy. A key component of this program is the development of a stable platform capable of meeting the requirement of flying in a ten meter tube on a path of up to 200 kilometers. The NASA C-20A/GIII (Fig. 1) was selected as the transitional vehicle for the UAVSAR program.

II. PPA SYSTEM REQUIREMENTS

The PPA must meet the following requirements to attain mission success [2]:
1. The vehicle will fly within a ten meter diameter tube for at least 90 percent of each pass in conditions of calm to light atmospheric disturbances.
2. The PPA will be able to operate between an altitude of 2,000 meters (6,560 feet) and the maximum attainable altitude with the pod attached, up to 13,700 meters (45,000 feet).
3. The PPA will use a waypoint file provided by JPL that will contain the start and stop locations and altitude for the precision pass.

III. PPA HARDWARE ARCHITECTURE

To minimize the impact of the GIII certification, the project elected to input signals through the navigation receiver (Glideslope/ pitch and Localizer/ roll) to the Flight Director/Autopilot as seen in Fig. 2 [3]. An advantage of this approach is to preserve the safety limits of the GIII Flight
The Platform Precision Autopilot (PPA) system architecture.

**IV. PPA SOFTWARE**

The Platform Precision Autopilot software is composed of three main subsystems: Navigation, Guidance, and Controller [5].

The Navigation subsystem consists of a loosely-coupled 12-state Kalman filter. The Kalman filter combines dGPS ECEF position (1 Hz) with Inertial Navigation System velocities (16 or 32 Hz) from DCAPS to generate a near real-time position solution in the form of latitude, longitude, and altitude. Additionally, the Navigation subsystem outputs error flags and a navigation valid flag that will be incorporated into an automatic fault detection system to warn the user of an error and manually or automatically disengage the PPA.

The Guidance subsystem allows the selection of either pressure or navigation altitude. The path can be either geodetic great earth circle or constant heading loxodromic. Additional inputs include current navigation position, beginning and ending waypoints and desired reference altitude. The Guidance subsystem generates cross track and altitude error, and drives a ten meter tube flag. The ten meter tube flag indicates when the combination of the cross track error and altitude error are within a five meter radius of the desired track.

The Controller subsystem generates a correction in response to altitude and cross track errors. The Glideslope (pitch) and Localizer (roll) axes are controlled by using PID feedback. In the pitch axis, vertical acceleration feedback is also incorporated to minimize accelerations in turbulence.

**V. MONTE CARLO RESULTS**

Monte Carlo analysis was conducted with a NASA Dryden GIII 6-DOF simulation. Monte Carlo testing consisted of randomly cast simulation parameters within specified bounds with and without turbulence [6]. Approximately 50 simulation parameters, such as aerodynamics, mass properties, system timing, and winds, were perturbed. Each aerodynamic and mass property parameter is individually perturbed.
varied by up to ±20 percent. For each test case, the wind direction and velocity is randomly selected. For that case, the wind can be from any direction, and the velocity anywhere between 0 and 100 knots. Five hundred simulation runs were conducted at each specific flight condition (altitude and Mach number) with and without turbulence. At 10,668 meters (35,000 feet) - Mach 0.75 without turbulence, shown in Fig. 3, all five hundred (100 percent) were successful in continuously tracking within the ten meter tube. In the presence of light/moderate turbulence, 95 percent of the cases continuously tracked within the ten meter tube, as demonstrated in Fig. 4.

VI. HARDWARE IN THE LOOP RESULTS

The PPA hardware is validated using the Hardware in the Loop (HIL) simulation where all the PPA external hardware interfaces are simulated in real-time. The GIII 6-Degree Of Freedom simulation is required to drive the AIC in real-time using flight equivalent hardware and software interfaces. This requires simulation of the differential GPS inputs and DCAPS data, and control loop closure based on the analog outputs (Glideslope and Localizer signals) generated by the AIC. The simulation interfaces are shown in Fig. 5.

The HIL simulation was used to develop and validate the PPA hardware and software. The HIL tests confirmed the flight hardware functioned as expected compared to software-only tests. Additionally, failure modes were analyzed and were determined to not be a safety of flight issue. Fig. 6 shows a sample of HIL data run with light/moderate turbulence demonstrating results similar to those of Monte Carlo testing.
VII. CONCLUSION

With the PPA system, an experimenter need only enter waypoints and a desired altitude. The PPA then generates commands that allow the UAVSAR to fly within a five meter radius of the defined path. It will also allow the same path to be flown again with similar tolerances. The experimenter may select an altitude anywhere between 6,096 meters (20,000 feet) and 13,716 meters (45,000 feet). The selected path can include nearly any position on the Earth’s surface.

Initial testing of the PPA demonstrates robustness to uncertainties or variations in the aircraft mass properties and aerodynamics. In calm to light turbulence, achieving ten meter tube accuracy was shown in up to 100 knot winds.

The PPA system will have undergone flight testing by the time of this conference. A fully developed system is expected to be provided to the UAVSAR program later this year.

REFERENCES