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.

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.

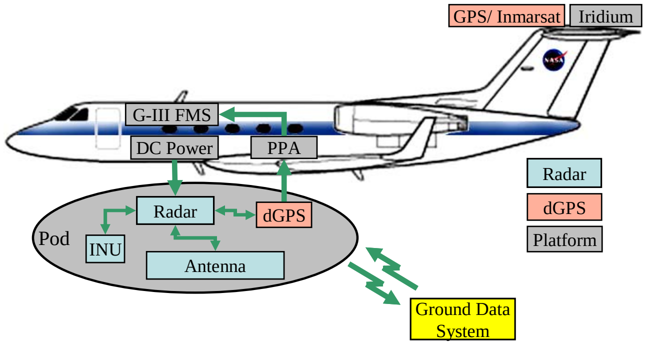

Fig. 1. UAVSAR Aircraft Configuration with a Synthetic Aperture Radar Pod.

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

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

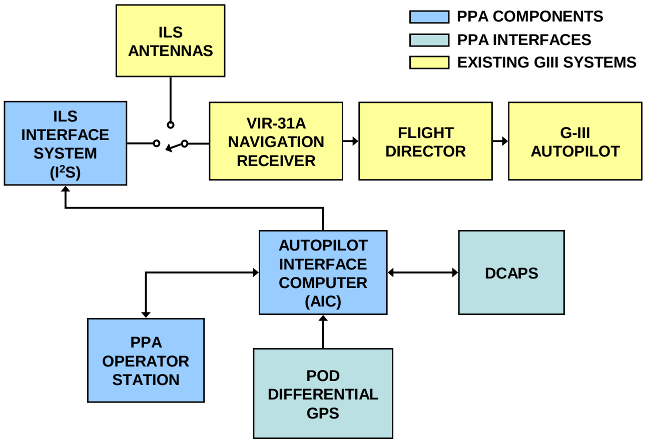

Fig. 2. Platform Precision Autopilot (PPA) system architecture.

Director and Autopilot. Challenges that this approach presents include the following:

1. The navigation receiver requires a modulated radio frequency. This requires additional frequency modulation hardware between the controller and the navigation receiver.
2. The navigation receiver introduces noise, scaling, and offsets which reduce the accuracy and precision of the controller.
3. The Flight Director has other control inputs that determine output, such as vertical velocity and roll angle. This may result in unexpected results for the GIII flight path.
4. The Flight Director has variable scaling of navigation receiver inputs. This effectively changes the control system gains which influence closed loop performance.

An inversion of the above effects is required to ensure that the correct PPA command reaches the GIII baseline autopilot.

The PPA software is hosted on the Autopilot Interface Computer (AIC), a Phytec MPC565 Single Board Computer operating at 56 MHz. The AIC provides interfaces to three external data sources, the differential GPS (dGPS), Data Collection and Processing System (DCAPS), and the Operator Station. The AIC also outputs control signals to the Instrument Landing System (ILS) Interface System (I2S), which is in turn connected to the navigation receiver.

The two sources of data to the PPA are JPL's dGPS unit and the DCAPS. The differential GPS unit, developed by JPL, provides earth centered earth fixed (ECEF) positions in meters. It achieves high accuracy using two sources of GPS correction (Inmarsat and Iridium) and two differential GPS units. Four solutions are computed and the best solution is automatically selected. The dGPS position accuracy is estimated at 10 centimeters horizontally and 20 centimeters vertically (1sigma) at 1 Hz.

The second source of data is DCAPS, which samples aircraft sensor data from the GIII ARINC-429 data bus [4].

The PPA Operator Station is software which serves the following functions:

1. Displays and records data
2. Selects altitude and path type
3. Initializes navigation routine
4. Initiates built-in-tests
5. Engages/disengages precision autopilot

In summary, the PPA hardware consists of the AIC and takes advantage of the GIII avionics. In spite of the above challenges, the current hardware architecture is capable of meeting the performance requirements while maintaining the GIII FAA certification.

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

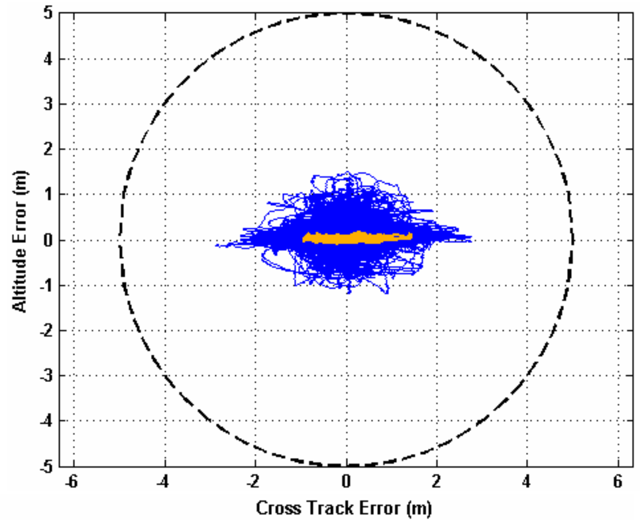

Fig. 3. Results from a 500-run Monte Carlo study shows aircraft flying the ten meter tube in calm air at 10,668 meters (35,000 feet) - 0.75 Mach.

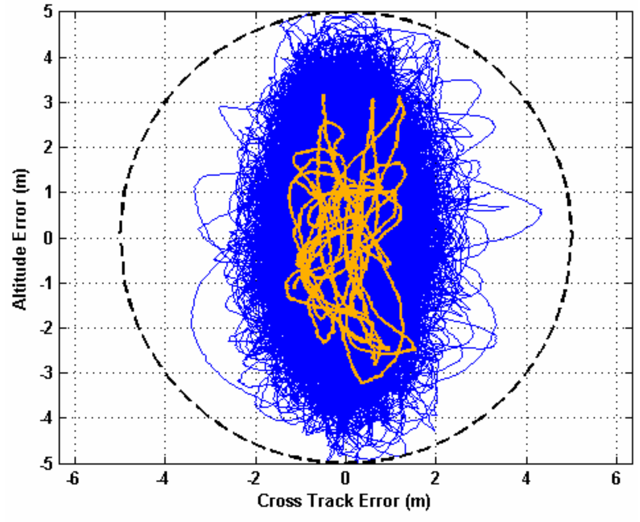

Fig. 4. Results from a 500-run Monte Carlo study shows aircraft flying the ten meter tube with light/ moderate turbulence at 10,668 meters (35,000 feet) - 0.75 Mach.

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.

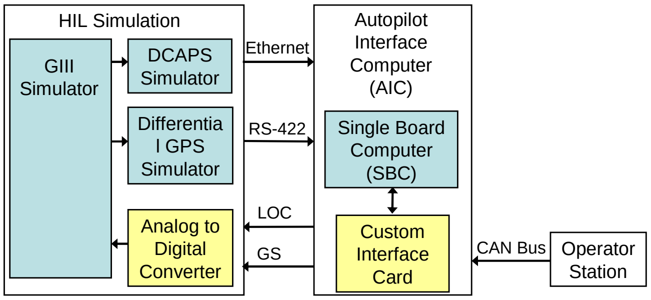

Fig. 5. The Hardware in the Loop simulation interfaces with the Autopilot Interface Computer and the Operator Station.

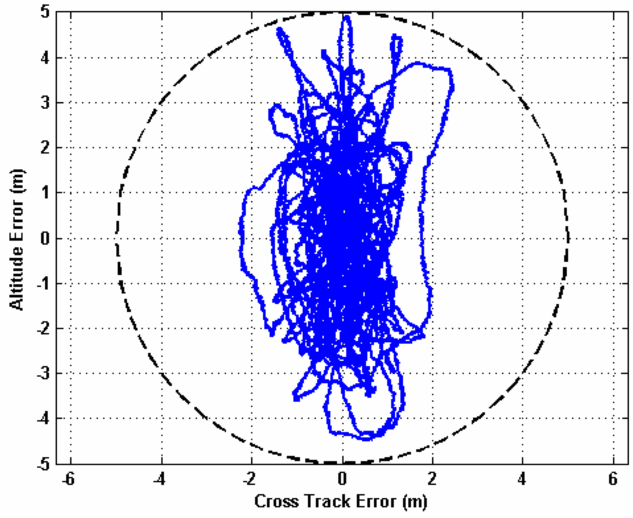

Fig. 6. Hardware in the Loop tests demonstrated similar results as Monte Carlo testing at 10,668 meters (35,000 feet) - 0.75 Mach, with light/moderate turbulence.

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.

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