INTEGRATED INERTIAL/GPS

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SUMMARY

The presence of failures in navigation sensors can cause the determination of an erroneous aircraft state estimate, which includes position, attitude, and their derivatives. Aircraft flight control systems (AFCS) rely on sensor inputs to determine the aircraft state. In the case of integrated Inertial / NAVSTAR Global Positioning System (GPS), sensor failures could occur in the on-board inertial sensors or in the GPS measurements. The synergistic use of both GPS and INS allows for highly reliable fault detection and isolation of sensor failures. Integrated Inertial/GPS is a promising technology for the High Speed Civil Transport (HSCT) and the return and landing of a manned space vehicle.

BACKGROUND

The NAVSTAR Global Positioning System is expected to be operational by the year 1993. Presently, ten experimental satellites (Block I) and seven operational satellites (Block II) have been successfully launched and are undergoing tests. Navigation with the GPS is based on pseudorange and integrated Doppler shift measurements with respect to GPS satellites. In combination with ephemeris information, transmitted by the satellites, a receiver can determine its position and velocity with respect to the satellites with a positional accuracy of 16 meters (Precise Positioning Service) and with a velocity accuracy of better than 0.1 meter per second. Differential GPS can result in navigational accuracies of better than 3 meters for pseudoranging and well within 0.2 meter using integrated carrier phase measurements. The GPS satellite signals can also be used to determine aircraft attitude by making interferometric measurements with a minimum of three separate antennas (ref. 1). GPS interferometric attitude determination is expected to be within 0.1 degree for pitch, roll, and yaw angles.

Because of the capabilities described above, the GPS can play an important role in the reliable state estimation of aircraft. Specifically, an integrated Inertial/GPS system could provide continuous, high-accuracy attitude information, three-dimensional position and velocity, and time. The system could also provide a high level of fault tolerance, since GPS and inertial measurements provide similar information.

The overall objective of an integrated Inertial/GPS system is to provide reliable aircraft state estimates in the presence of possible failures in the GPS measurements and the on-board inertial sensors. This involves the design of fault tolerant algorithms, implementation and flight demonstration of the integrated Inertial/GPS system. Previous research at Langley Research Center demonstrated the capability to provide dual fail-operational performance for a skewed array of inertial sensors (ref. 2). The redundant strapdown inertial measurement unit

(RSDIMU) used for this project will also be used for the laboratory and flight demonstration of Inertial/GPS techniques.

OVERVIEW OF RESEARCH

Current efforts are focused on the determination of the effective GPS data rate which involves GPS receiver tracking loop design and simulation, and on fault detection and isolation of GPS measurement errors. In the area of receiver autonomous fault detection, a novel signal processing technique has been applied to improve the effectiveness of fault detection algorithms in the presence of near collinearity (ref. 3).

The GPS receiver simulation program as presented in reference 1 is being extended to address the effect of tracking loop bandwidths of the code and carrier tracking loops on the effective GPS data rate. Figure 1 shows the block diagram of an integrated Inertial/GPS in combination with the AFCS. Both GPS and inertial data are combined by the estimator, which in turn provides the aircraft state estimates to the flight control system. The GPS data rate is required to facilitate the integration of GPS data into the aircraft flight control system, and to determine fault detection capabilities based on GPS attitude information.

Also continuing is the implementation of the integrated Inertial/GPS test bed. The RSDIMU system is currently available for data collection in the laboratory environment. The inertial system will be combined with a 4-channel GPS receiver. At the same time, provisions are being made to install the integrated system in Ohio University's Douglas DC-3 research aircraft, N7AP.

REDUNDANT STRAPDOWN INERTIAL MEASUREMENT UNIT

The inertial sensor used for this project is a Redundant Strapdown Inertial Measurement Unit (RSDIMU). A block diagram of the RSDIMU is shown in figure 2 (based on ref. 4). The inertial sensors consist of four two-degree-of-freedom accelerometers and gyroscopes arranged in two semi-octahedral arrays. These redundant arrays are interfaced to electronics boxes which contain analog-to-digital converters. The sensor data are processed by two flight computers. The magnetic tape drive is used for in-flight program loading. Also used during system testing is a printer for real time data output and a control panel to operate the system and to inject failures into the measurement data. Power to the inertial sensors is provided through a power back-up unit, which allows the sensors to operate for about 20 minutes in the absence of aircraft power.

The performance of the inertial sensors would support navigation accuracies on the order of 2 nautical miles per hour. However, the inertial system is only required to provide short-term navigation data. The GPS will provide the long-term navigation stability for this system.

RSDIMU NAVIGATION MODE PROGRAM FLOW

The RSDIMU has several modes of operation, including coarse and fine alignment, and navigation. Figure 3 shows the flow diagram for the navigation mode. Each navigation cycle is initiated by a sensor interrupt. The raw sensor data are then scaled and converted to floating point representation. Next, fault detection and isolation routines are carried out, and some data are fed back to the IMU sensors for corrections. Finally, attitude information is output to the flight control system and the navigation solution is updated. The subsequent sensor interrupt initiates the next run through the navigation update cycle. The system operates at an update rate of 64 updates per second.

GPS RECEIVER

A four-channel GPS receiver employing continuous carrier tracking is used for this project. Figure 4 shows a simplified block diagram of the GPS receiver tracking loops. The bandwidth of the code tracking loop is as small as 0.01 Hertz when the receiver is in continuous tracking. The carrier tracking loop bandwidth is 32 Hertz and is used to update the code tracking loop every millisecond to correct for dynamics which cannot be tracked by the code loop. The GPS carrier wavelength at 1575.42 MHz is approximately 19 cm, which provides a tracking resolution of better than 1 cm. In addition, the carrier tracking loop is a second order system which has less than 20 degrees of phase lag at line-of-sight accelerations of up to 40 m/s^2, which corresponds to a tracking error of less than 1 cm. The continuous carrier tracking is essentially a dead-reckoning input, similar to Doppler radar.

APPLICATIONS

The integration of GPS and INS has been targeted for several possible applications. These applications actually define the overall system requirements. One application is the High Speed Civil Transport (HSCT). GPS/INS can be used for heading and attitude determination. The return of a Space Shuttle from orbit or a Manned Return Vehicle (MRV) from a space station is another application. The inertial measurement would provide the short-term stability required by the flight control system. Differential GPS would be used in the terminal area to greatly improve landing accuracy and to enable the use of candidate landing sites throughout the world without the need for a dedicated landing system installation.

CONCLUSIONS

The synergistic integration of inertial measurements and the GPS operated stand-alone or in the differential mode has many promising applications in the areas of reliable aircraft state estimation and for use in terminal and landing operations. The RSDIMU test bed is operational in the laboratory environment, and is being integrated with a GPS receiver to implement and evaluate the above applications and to develop fault detection and isolation algorithms.

REFERENCES

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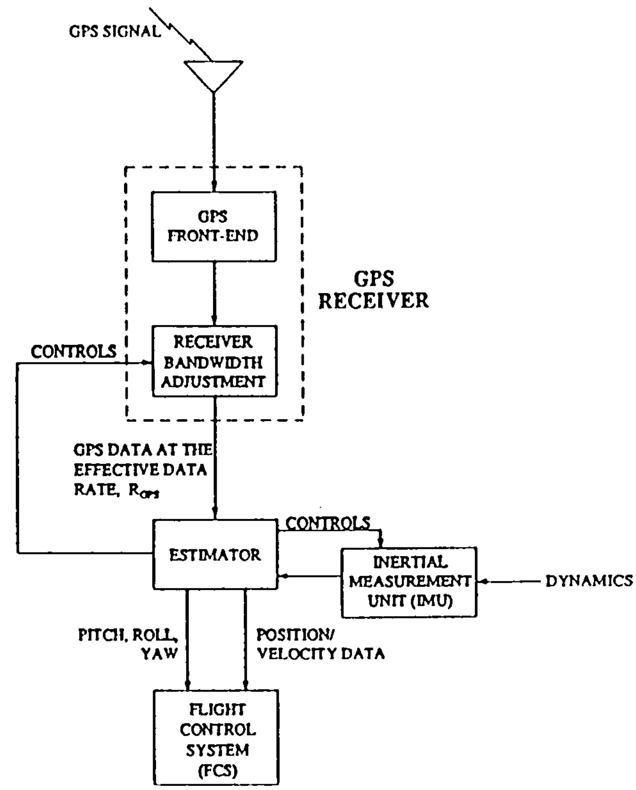

Figure 1. Integrated Inertial/GPS in combination with the Aircraft Flight Control System.

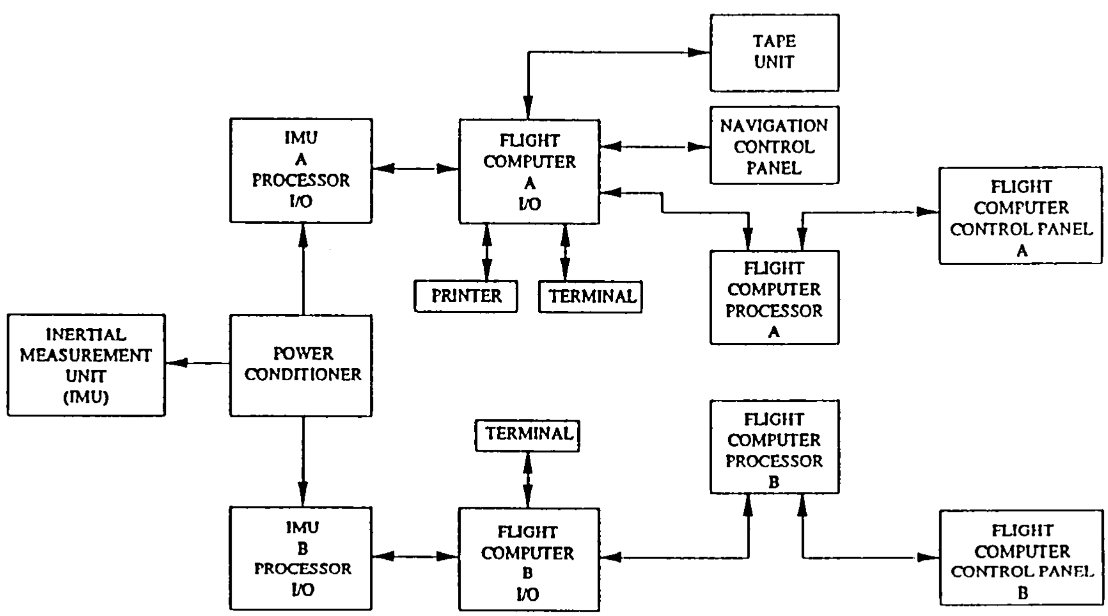

Figure 2. Block diagram of the Redundant Strapdown Inertial Measurement Unit (RSDIMU) (based on ref. 4).

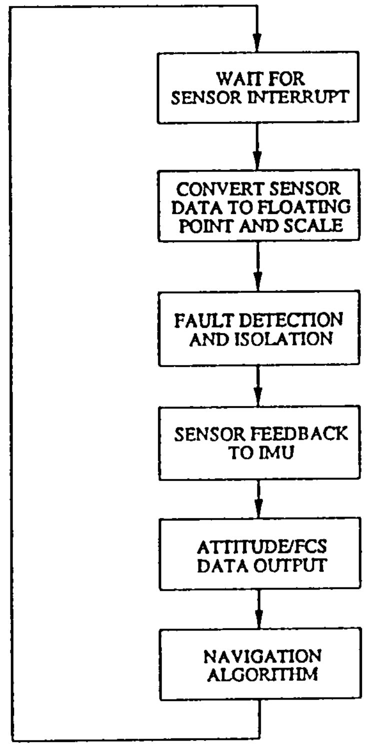

Figure 3. RSDIMU navigation mode flow diagram.

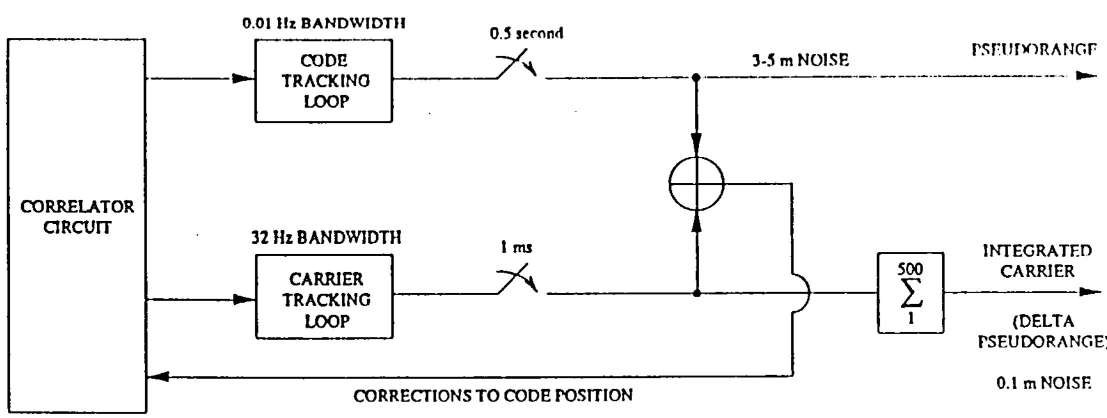

Figure 4. GPS receiver simplified block diagram of the code and carrier tracking loops.