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Divakaruni

[54] GPS/IRS GLOBAL POSITION DETERMINATION METHOD AND APPARATUS WITH INTEGRITY LOSS PROVISIONS

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- [58] Field of Search 342/357, 450,

342/457; 701/213, 214

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[57] ABSTRACT

A system for use with an inertial reference system and a global position receiver for calculating a position error after a loss of integrity by utilizing the global position system values for position and velocity at a time just before the loss of integrity and by utilizing the inertial reference system position modified by the known error in inertial reference system position as it varies with time and the position error as calculated by the global position system velocity extrapolated over the time since integrity loss.

19 Claims, 3 Drawing Sheets





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GPS/IRS GLOBAL POSITION DETERMINATION METHOD AND APPARATUS WITH INTEGRITY LOSS PROVISIONS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention pertains to a system employed for determining the global position of a mobile unit by employ-¹⁰ ment of both an inertial reference system (IRS) and a satellite positioning system (GPS), and more specifically, a system which employs a provision for determining the mobile unit's global position and corresponding integrity during those periods of time in which the GPS satellite ¹⁵ constellation is insufficient for establishing GPS integrity limit values by employment of RAIM.

2. Description of the Related Art

Satellite positioning systems are now well-known in the art. Such systems, for example, NAVSTAR-GPS, are rapidly ²⁰ being employed for a determination of the geocentric position of mobile units, such as water and land vehicles, space and aircraft, and survey equipment, to name a few.

In aircraft, GPS systems are being utilized for navigation, flight control, and airspace control. These GPS systems may operate independently or in combination with inertial reference systems or attitude heading reference systems in order to provide information particularly during a flight mission.

Global positioning systems, hereinafter referred to as "GPS", similar to NAVSTAR, commonly use a GPS receiver, located on a mobile unit, for receiving satellite information signals transmitted from a plurality of satellites. Each GPS satellite transmits a satellite information signal containing data that allows a user to determine the range or distance between selected GPS satellites and the antenna associated with the mobile unit's GPS receiver. These distances are then used to compute the geocentric position coordinates of the receiver unit using known triangulation techniques. The computed geocentric position coordinates may, in turn, be translated to earth latitude and longitude coordinates.

In order to determine the position of the GPS receiver, a minimum of four unique satellite information signals are required, rather than the expected three (three position, 45) unknown coordinates). This is so, since the GPS receiver generally includes a receiver clock which is not as accurate as the atomic clock normally associated with each of the satellites. Therefore, receiving satellite information signals from four different satellites provides a complete solution 50 which permits the correction of any receiver clock error as is well-understood in the art. Herein, the GPS receiver position derived by the triangulation technique using data from multiple satellites is referred to as the "GPS estimated position", identified as POS_GPS. The accuracy of this 55 estimated GPS position is dependent upon many factors, including, among others, atmospheric conditions, selective satellite availability, and the relevant position of the satellites with respect to the line of sight view of the satellites.

Associated with a GPS estimated position is a "position 60 error bound" as particularly defined by accepted GPS systems standards which have been developed by the Radio Technical Commission for Aeronautics (RTCA), in association with aeronautical organizations of the United States from both government and industry. The RTCA has defined 65 the phrase "GPS system integrity" as the ability of a GPS system to provide timely warnings to users when the GPS

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system should not be used for navigation. "System integrity" is particularly identified in a document entitled "Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)", document number RTCA/DO-208, July 1991, prepared by: SC-159, beginning at section 1.5. As described therein, GPS is complicated in that it is a fourdimensional system involving three components of position and one time component. As also described in the aforesaid RTCA publication, the signal-in-space error transforms into a horizontal position error via a relatively complex function of a satellite constellation geometry at any given moment. The GPS integrity system must interpret the information it has about the received GPS signals and error terms in terms of the induced horizontal position error, commonly referred to as the "position error bound", and then make a decision as to whether the position error bound is outside the allowable radial error, specified for a particular phase of the flight mission in progress. The allowable error is referred to as the "alarm limit", herein referred to as the "integrity alarm limit". If the horizontal position error bound is found to exceed the integrity alarm limit, a timely warning must be issued by the GPS receiver or subsystem to notify the pilot that the GPS estimated position should not be relied upon.

Two rather distinct methods of assuring GPS integrity have evolved as civilian use of GPS has progressed. One is the Receiver Autonomous Integrity Monitoring (RAIM) concept, and the other is the ground monitoring approach that goes under the "GPS Integrity Channel" (GIC). The intent of both of these methods is the calculation of the position error bound with regard to the current GPS estimated position so that it may be compared with the alarm limit associated with a particular phase of a flight mission.

The receiver autonomous integrity monitoring system (RAIM) employs a self-consistency check among the 35 measurements, more specifically, GPS pseudo range measurements. Satellite redundancy is required to perform a self-consistency check on an instantaneous basis. Thus, five satellites must be in view, i.e., five satellite information signals received and pseudo range measurements calculated by a GPS receiver. If fewer than five satellites are in view, the value of the predicted position error bound will be infinite. Also, constraints are placed on the satellite constellation geometry that must be met if the self-consistency check is to be effective in the presence of noise, e.g., azimuth angle of the satellite relative to user position. Generally, a satellite constellation with many satellites in view permits a robust integrity monitoring system. Conversely, a satellite constellation having only a few satellites in view, may limit the availability of an integrity monitoring system. Thus, there may be short periods when a good consistency check is not possible (less than five satellites in view). The main feature of RAIM is that it is completely self-contained and relatively easy to implement in software.

Examples of RAIM may be found in the aforementioned RTCA publication, Appendix F, and also in an article entitled "Implementation of a RAIM Monitor and a GPS Receiver and an Integrated GPS/IRS" by Mats Brenner, located at page 397, in the proceedings of ION GPS-90, Third International Technical Meeting of the Satellite Division of the Institute of Navigation, Sep. 19–21, 1990.

GPS systems which incorporate RAIM output a position error bound value which represents the probabilistic radial errors of the navigation solution, namely, the GPS estimated position of the receiver unit. Currently, RAIM may generate several numbers, including, a horizontal position error bound value (sometimes referred to as HIL—Horizontal

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