Integration of GPS with a Rubidium Clock and a Barometer for Land Vehicle Navigation

Zhaonian Zhang, *Department of Geomatics Engineering, The University of Calgary*

BIOGRAPHY

Zhaonian Zhang is a MSc student in the Department of Geomatics Engineering at the University of Calgary. He received a B.Sc. in Electrical Engineering from Southeast University, China in 1982, and a MSc in Electrical Engineering from Northwestern Polytechnical University, China in 1988.

ABSTRACT

An integrated navigation system consisting of GPS with a rubidium clock and a barometer is developed and investigated for land vehicle navigation. In order to evaluate the performance of the integrated navigation system, a field test in an ideal environment with excellent satellite coverage and geometry was conducted. Post-mission precise satellite orbits and clock corrections were used to reduce the effects of SA. The test results have shown that the integration of GPS with a rubidium clock and a barometer provides significant improvement in the vertical accuracy. A virtual wall satellite rejection algorithm was implemented to simulate urban areas, where GPS outages occur frequently. The integrated navigation system was proven capable to navigate using three or two satellites with acceptable accuracy for vehicule navigation.

INTRODUCTION

Almost all land vehicle navigation systems include GPS as the main technology. However, as is well known, it requires at least four satellites available to estimate vehicle's position from GPS. In urban areas and/or along tree-lined roads, where the satellite signals are masked by the tall buildings and/or trees, the GPS outages occur frequently and fewer than four valid satellite measurements are obtained at each update. There is interest in the development of navigation systems capable to position a vehicle using only two or three satellites.

Time/altitude aided GPS is one means to maintain the quality of the navigation during an outage. The previous work on exploiting time/altitude aided GPS dealt with time aiding from a cesium beam reference and accurate altitude aiding from a radar altimeter (Dayton et al. 1988, Bridges 1988). This study investigates the integration of GPS with a lower cost clock and altimeter, namely, a rubidium clock and a barometer, while focusing on its performance for land vehicle navigation.

SYSTEM HARDWARE

The integrated navigation system consists of a NovAtel GPSCard 951R GPS receiver, an Efratom Model FRK-LLN Rubidium clock, a GPS Silicon Valley GPS Reference Frequency Generator, a Viatran Model 246 barometric pressure transducer, an Advantech PCL-711 12-bit data acquisition board and an IBM compatible computer as shown in Figure 1.

The Efratom Model FRK-LLN Rubidium clock is a compact, atomic resonance-controlled oscillator, which provides an extremely pure and stable sinusoidal signal of 10 MHz. The GPS Silicon Valley GPS Reference Frequency Generator provides an externally generated reference clock signal for the NovAtel GPSCard. The generator card generates the 20.473 MHz reference signal as required by the GPSCard. This signal is phase locked to the rubidium clock. The GPSCard, the GPS reference frequency generator and the Advantech

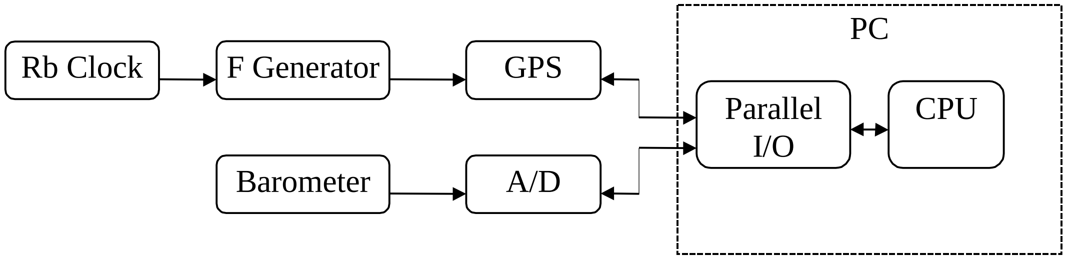

Figure 1. Hardware overview - integrated navigation system

PCL-711 12-bit data acquisition board are all PC compatible circuit boards, and installed in the expansion slots of the PC.

The Viatran Model 246 barometric pressure transducer is used to measure barometric pressure and translate it into an output of voltage ranging from zero to five volts. The voltage output is converted by the PCL-711 data acquisition board.

NAVIGATION SYSTEM DESIGN

The integrated navigation system is designed to be modular and decentralized, as shown in Figure 2. GPS is chosen as the reference filter because its system model has the most extensive state vector of position and velocity. Each sensor has its own local filter with its states being the subset of the reference filter.

When the number of satellites in view is more than three and the satellite geometry is sufficiently good (HDOP<5), the adaptive filter will estimate the receiver clock offset from GPS measurements; the Kalman filter for the barometer will calibrate the barometer, that is, estimate the barometric height error from GPS height measurement. With GPS pseudo-range, Doppler measurements and the improved clock offset, the master Kalman filter will provide a better estimation of the position.

When the number of satellites in view falls to three or two, or the satellite geometry with more than three satellites is too poor, the adaptive filter will predict the clock bias and the Kalman filter will predict the barometric height error. The master Kalman filter can still estimate the position with acceptable accuracy.

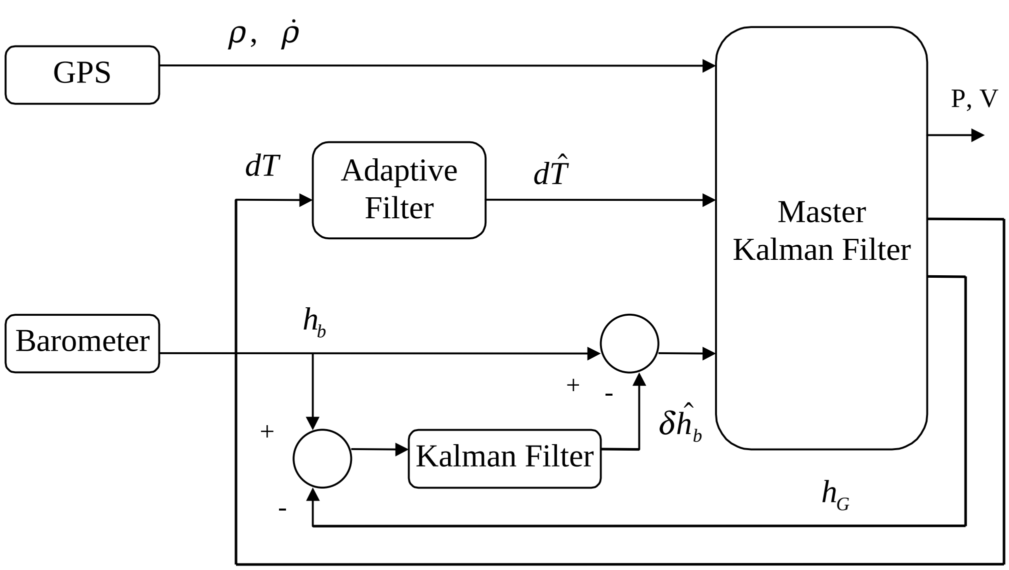

Figure 2. Block diagram of the decentralized integrated navigation system

The integrated navigation program was developed using software C^3NAV^{TM} (Cannon & Lachapelle 1992), to implement the algorithm of the system design.

FIELD TEST PROCEDURE

A field test was carried out at Nose Hill Park, Calgary in November 1996. To obtain a reference trajectory at the decimeter accuracy level from carrier phase measurements, this ideal environment with excellent satellite coverage and geometry was chosen.

The navigation system was mounted on a vehicle. The antenna of the GPS receiver was installed on the top of the car. Another NovAtel GPSCard receiver was used as the reference station, placed on the roof of the Engineering Building at the University of Calgary, some 5 to 10 km away.

L1 code, carrier phase and barometric pressure measurements were collected at one second intervals over one and half hour. The vehicle was kept stationary for twenty minutes before moving to allow the rubidium clock to stabilize. A reference trajectory, accurate to a few decimeters, was obtained using the full GPS constellation with a float ambiguity solution approach. This accurate reference trajectory is used to evaluate the accuracy of subsequent solutions.

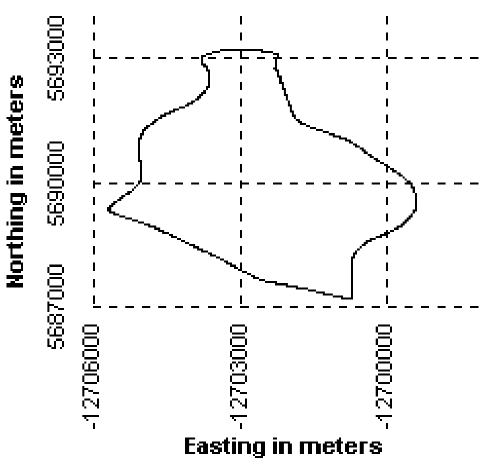

Figure 3. Horizontal reference trajectory

In order to evaluate the integrated navigation system in stand-alone mode, the data was processed in the following ways:

1) GPS only (unaided GPS) in an ideal environment (with excellent satellite coverage and geometry): point

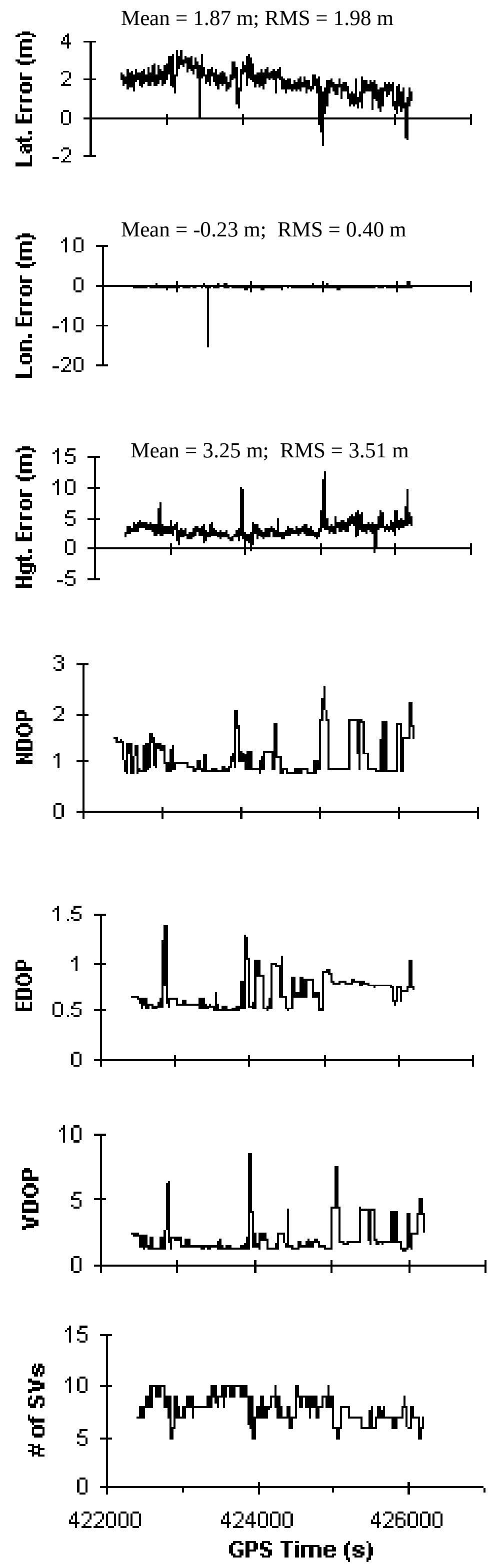

Figure 4. Positioning errors of unaided GPS in an ideal environment, where the satellite coverage and geometry are excellent.

positioning results were computed by least squares using all satellites in view;
2) integrating GPS with a rubidium clock and a barometer in an ideal environment: point positioning results were computed by the integrated navigation program (Kalman filter) under the same condition as in 1);
3) integrating GPS with a rubidium clock and a barometer for a simulated downtown area: some satellites were assumed to be blocked by virtual walls with cross track cutoff angle of seventy degree, then point positioning results were computed by the integrated navigation program using the remaining satellites in view.

All of the above processing intervals were one second for all measurements. C/A code position solutions were computed using a satellite cutoff angle of five degrees. Tropospheric corrections were included in all results. To reduce the effects of Selective Availability (SA), post-mission information was used. This information consists of precise orbits (<0.5 m) and satellite clock corrections (< 1 ns) and is obtained from NRCan (Heroux et al. 1993).

RESULTS

Unaided GPS in an Ideal Environment

Stand-alone unaided GPS positioning was performed using precise satellite orbits and clock corrections for the ideal environment.

Figure 4 shows the position errors of stand-alone positioning, DOPs and the number of satellites in view. One-to-three meter level of positioning accuracy can be achieved by overcoming SA because of the use of post-mission information.

Biases are significant on both horizontal and vertical error components. They are believed to be mainly due to the effect of ionosphere. It is also noted that when the number of satellites in view falls to five, the VDOP increases significantly, which results in a significant degradation in the vertical accuracy.

Integrating GPS with a Rubidium Clock and a Barometer for an Ideal Environment

The stand-alone GPS integrated with a rubidium clock and a barometer was performed using precise satellite orbits and clock corrections for an ideal environment. Figure 5 presents the position errors in stand-alone mode.

By comparing Figure 5 with Figure 4, it is noted that while the horizontal accuracy of the integrated GPS is almost the same as that of unaided GPS, the vertical accuracy is improved significantly by the integrated GPS. This is because the adaptive filter can provide a more accurate estimate of the receiver clock offset, and the clock offset error is almost linearly correlated only to the vertical error. The worse the geometry, the higher the correlation between the clock offset error and position errors (both vertical and horizontal errors). The improvement in the vertical accuracy is especially important for calibrating the barometer.

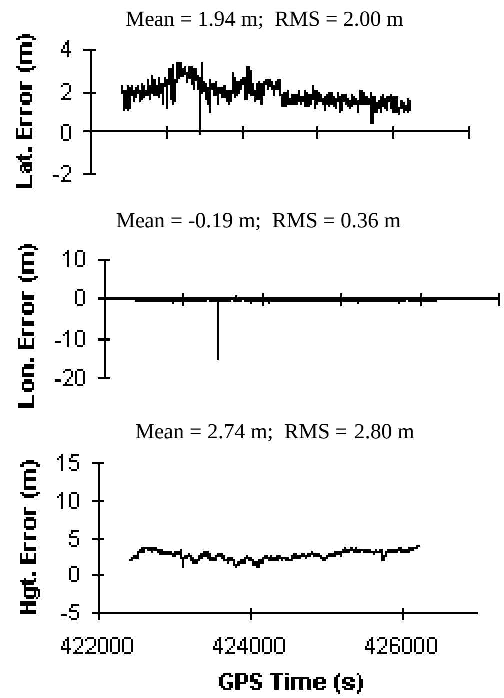

Figure 5. Positioning errors of the GPS integrated with a rubidium clock and a barometer in the ideal environment.

Integrating GPS with a Rubidium Clock and a Barometer for a Simulated Downtown Area

A virtual wall satellite rejection algorithm, which builds two virtual walls on both sides of the road, was implemented to simulate downtown areas (Hayashi 1996). The walls block a part of the sky and mask the signals of some satellites. A cross track cutoff angle of seventy degrees was chosen, which corresponds to a wall height of 20 meters under the assumption that the cross track distance from the vehicle to the walls is 7.5 meters.

Figure 6 shows the number of satellites in view for the simulated downtown area. During most of the time, the number of satellites in view is two or three. The unaided GPS can provide position solution only in a very short period of time (90 seconds out of 3800 seconds), during which four satellites can be seen in a reasonable geometry.

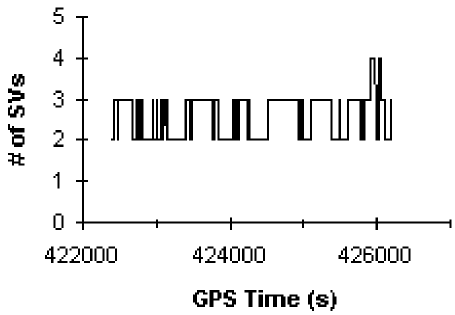

Figure 6. The number of satellites in view for a simulated downtown area.

Stand-alone GPS integrated with a rubidium clock and a barometer was performed using post-mission precise satellite orbits and clock corrections for the simulated downtown area. Before the vehicle enters the simulated downtown area, all the satellites in view in the ideal environment were tracked by the receiver to allow the integrated navigation system to estimate the clock offset and calibrate the barometer. The stand-alone positioning results in the simulated downtown area are shown in Figure 7.

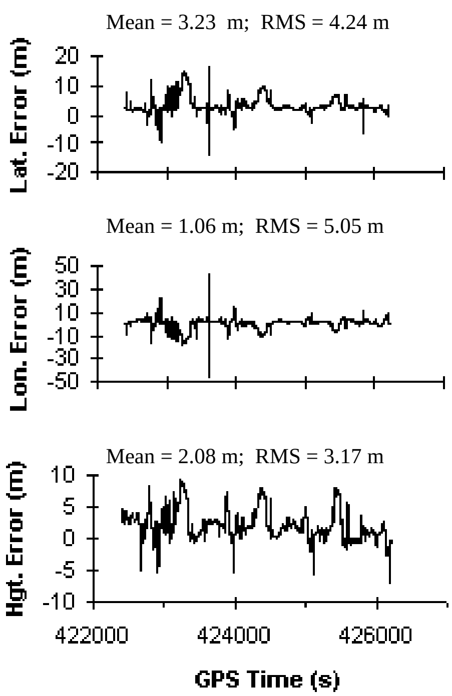

Figure 7. Positioning errors of GPS integrated with a rubidium clock and a barometer for the simulated downtown area.

The integrated navigation system is capable to navigate using two or three satellites in the entire simulated downtown area (3800 seconds), although the accuracy is reduced. When the number of satellites in view is three or two, the Kalman filter holds the last barometric height bias obtained from the estimate of GPS height with good geometry. The vertical accuracy of the integrated navigation system is dependent upon both the calibration accuracy and the clock and barometer accuracy. For land vehicle navigation, the atmosphere and temperature are relatively stable in the local area. The barometer, therefore, demonstrates an unexpectedly good performance. In addition, the horizontal errors show strong correlation to the vertical error.

CONCLUSIONS

The integration of GPS with a rubidium clock and a barometer is an effective means to improve the performance of navigation for land vehicle navigation. The field test reported herein has proven that it provides a better vertical accuracy, and the simulated test has shown that it is able to navigate using two or three satellites with acceptable accuracy, provided the geometry of the remaining satellites is adequate. Further field tests are being conducted in downtown areas to evaluate the integrated navigation system augmented by a drift rate gyro (Zhang 1997).

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