Satellite/Inertial Navigation and Positioning System (SINAPS)

Functional Requirements List and Performance Specifications

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Submitted
Tuesday, November 24, 2009

Introduction

The goal of the S.I.N.A.P.S. project is to integrate inertial sensors and a GPS unit into a unified, low-cost navigation system. The inertial measurement unit (IMU) will have nine degrees of freedom from magnetometers, accelerometers, and gyroscopes with respect to each axis $(x, y, z) \in \mathbb{R}^3$. Cheaper IMU devices are built with micro electromechanical system (MEMS) sensors which constantly accumulate errors, resulting in a position 'drift' that will give increasingly incorrect solutions. On the other hand, a standalone GPS unit can be error prone as well if there is anything blocking the open sky such as tall buildings or mountain ranges. The motivation for this project is that the fusion of both devices can produce accurate, robust navigation at a low cost. The final system will be accurate within a few meters, making it adequate for automobile and pedestrian tracking, sports applications like hiking and skiing [1], and for missile guidance. However, the S.I.N.A.P.S. system will not be suitable for autonomous vehicle navigation, which requires sub-meter accuracy.

Functional Description

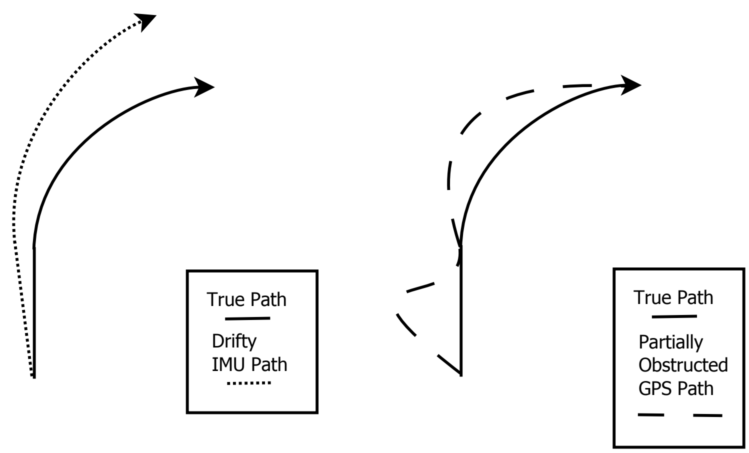

Figure 1: IMU and GPS Sources of Error

Figure 1 shows position and heading drift that may accumulated for a MEMS-based IMU. It also shows the potential for error when the GPS satellites become obstructed, thus giving unreliable position readings. While the GPS is in clear view of the sky it can correct the drift of the IMU, and in return the IMU can maintain navigability when the satellite signal is lost or distorted. Another goal of this project is to explore the robustness of the S.I.N.A.P.S. solution, such as how long the IMU navigates well before the accelerometer drift makes the system useless.

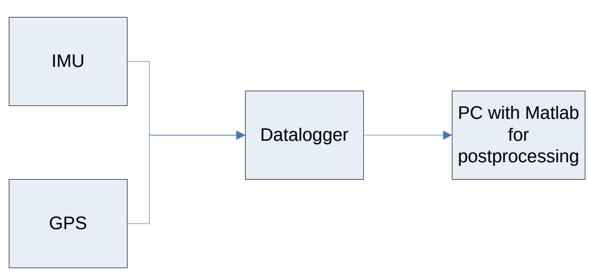

Figure 2: Hardware Overview

The GPS and IMU overall system is shown in figure 2. The GPS unit and IMU unit will both feed data into a logger which can send that data to a PC, where it can be processed in MATLAB or C. Currently the project is not going to run in real time, but the possibility is not being ruled out. Using a microcontroller or FPGA for real time tracking may be explored at a later date.

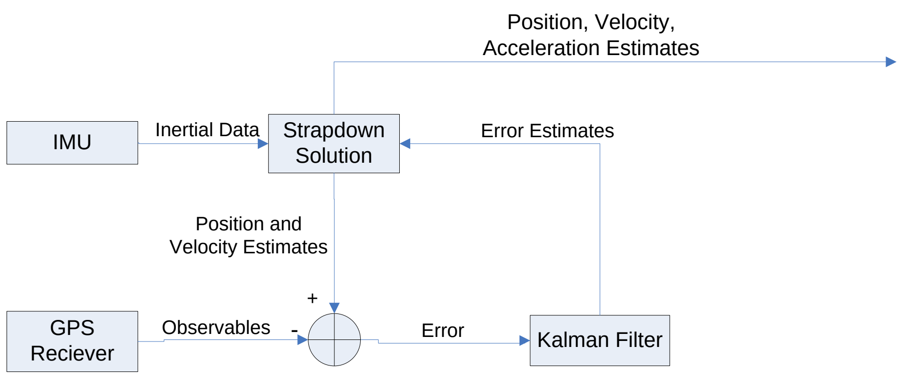

Figure 3: System Block Diagram

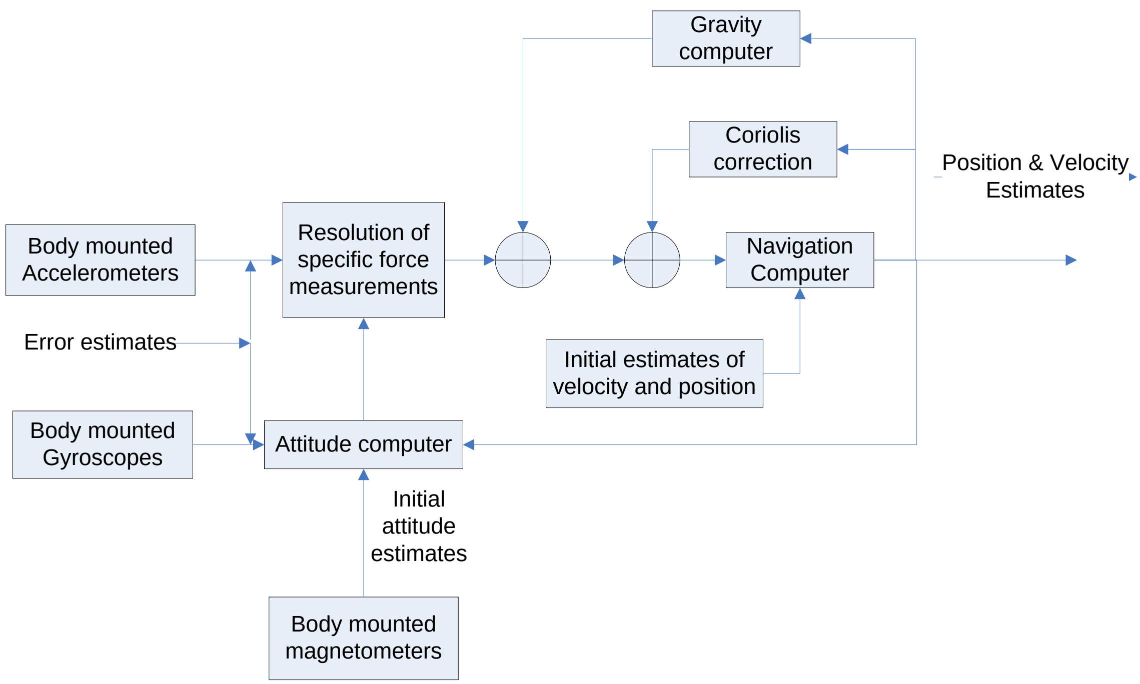

Figure 4: Strapdown Solution Software Diagram

The overall GPS/IMU relationship is shown in figure 3. The IMU will produce very fast, highly sensitive updates that need to be processed by strapdown solution software, which is detailed in figure 4. The strapdown solution is named so because the sensors are rigidly attached to a body, experiencing the same movement dynamics as the body itself [3]. Position velocity and acceleration information can be extracted from the accelerometers. Attitude and heading information will be acquired from the magnetometers and gyroscopes. The processed IMU data will then be converted to the coordinate system of the GPS to allow comparison between the IMU and GPS readings. This comparison will produce an error signal that will be fed into a state estimator, which will process the error and update the strapdown solution to correct various errors within the system.

Specifications and Functional Requirements

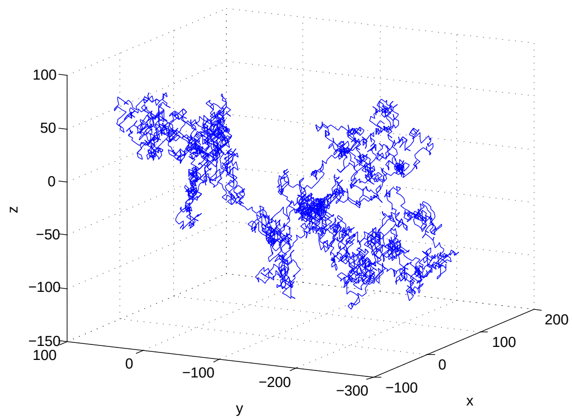

Figure 5: Random Walk Example

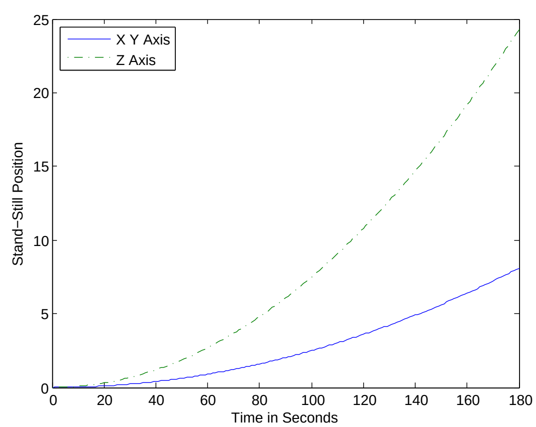

Figure 6: Position Drift, Standing Still

The accelerometers obviously only produce acceleration so that information will need to numerically integrated to obtain velocity and position. The complexity of the numerical integrator may be of no consequence (for example, Euler vs. Runge-Kutte integration), but that will not be known until the units themselves can be tested. The sources of errors will be modeled in a state-space system. In order to correct the errors a state observer will be implemented, specifically a form of the Kalman Filter. The complexity and linearity of the Kalman Filter is to be determined and will reflect how many sources of error are considered in the overall system. Potential sources of errors include a ”lever arm” effect due to the physical distance between sensors, GPS cycle bias, GPS clock bias ambiguity, position drift, random walk, and atmospheric interference disturbing the GPS.

For this project the Vectornav VN-100 IMU with development board will be used. The X-Y drift bias of this IMU is $0.5mg$ and the Z drift is $1.6mg$. To calculate a relative position drift integrate the drift values twice and plot over time. According to figure 6 after 3 minutes the XY position will be off by 8 meters and the Z axis will be off by 24 meters. The drift velocities are rather high for an inertial sensor, so the Kalman filter and GPS is absolutely necessary to correct for these errors. The GPS used is the Ublox GS 407 standalone reciever. It is equipped with satellite-based position correction using the Wide Area Augmentation Service, which will give position accuracy under 2 meters.

Ideally the sensor bias errors will trend to zero, but the random walk as shown in figure 5 will likely remain. Because the system is going to be designed for pedestrian or commercial automobile use it will be useful until the position drifts beyond 50 meters. If the GPS loses its location the Z axis IMU readings will be useful for about 4 minutes and the XY readings will be good up to 8 minutes.

References

[1] A. Waegli and J. Skaloud, *Optimization of two gps/mems-imu integration strategies with application to sports*, GPS Solutions, [Online], Available: {http://dx.doi.org/10.1007/s10291-009-0124-5}

[2] D.H. Titterton and J.L. Weston, *Strapdown Inertial Navigation Technology, 2nd Edition*, The Institution of Electrical Engineers, (2004)

[3] C. Verplaetse, *Strapdown Systems*, Created Friday, May 26, 1995, [Online], Available: {http://xenia.media.mit.edu/~verp/projects/smartpen/node8.html}