Satellite and Inertial Navigation and Positioning System

Project Proposal

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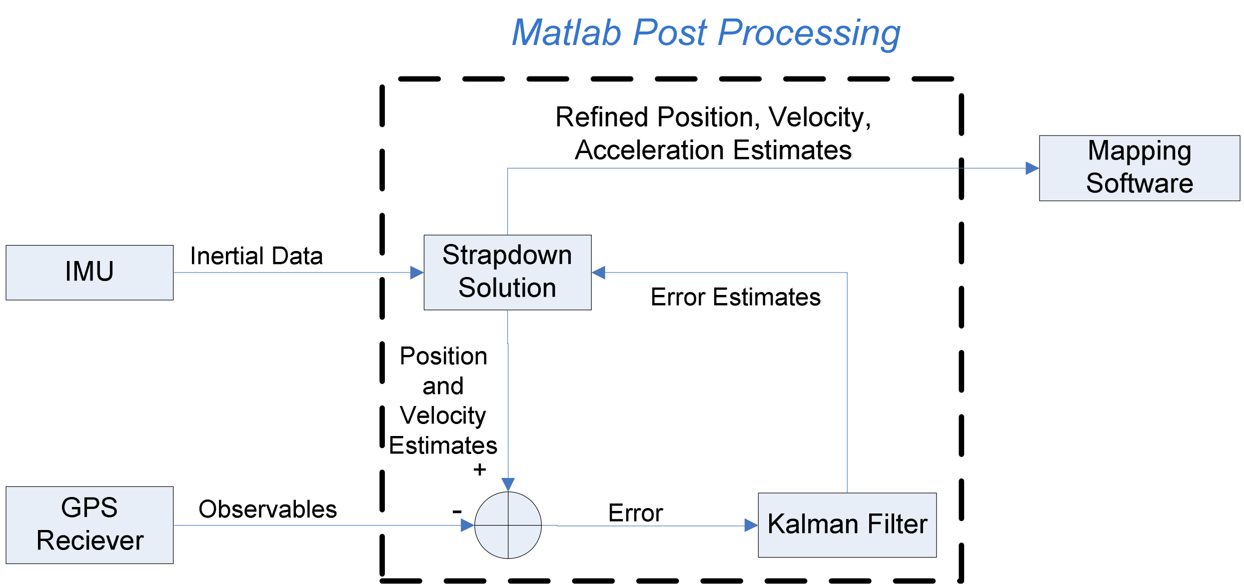
PROJECT SUMMARY

The SINAPS project will integrate an inertial measurement unit (IMU) and a global positioning system (GPS) into a robust and low-cost navigation system. GPS units are reasonably priced, but traditional IMUs cost tens of thousands of dollars; as such, this project will utilize a cheaper micro-electromechanical system (MEMS) based IMU. Alone, the IMU and GPS are error prone, but together each will compensate for the others shortcomings through post-processing. The final system will be accurate within a few meters.

HIGH LEVEL BLOCK DIAGRAM

There are two main types of GPS/IMU sensor-fusion known as tightly and loosely-coupled. Loosely coupled is easier to implement and performs position corrections at the output on the calculated IMU position estimates. The systems simplicity comes at the price of measurement reliability. Tightly-coupled systems can be several times more accurate and resistant to measurement error than loose-coupling (reference, urban GPS), but the system is more complicated because the correction is made directly to the accelerometer data. Figure 1 shows the high-level block diagram for the project. Inertial data from the IMU and pseudoranges (raw data) from the GPS are logged and sent to Matlab for post processing. There, the inertial data is passed through the strapdown solution to provide the initial position and velocity estimates. These estimates are then differenced with the GPS data and the error signal is sent to the Kalman filter. The Kalman filter then provides correction estimates, which are then fed back into the strapdown solution to directly correct drifty accelerometer and gyroscope measurements. The estimated position data from the strapdown solution will be sent into a mapping package, such as Google Earth, to provide a graphical representation of the location data.

FIGURE 1: TIGHTLY-COUPLED SYSTEM BLOCK DIAGRAM

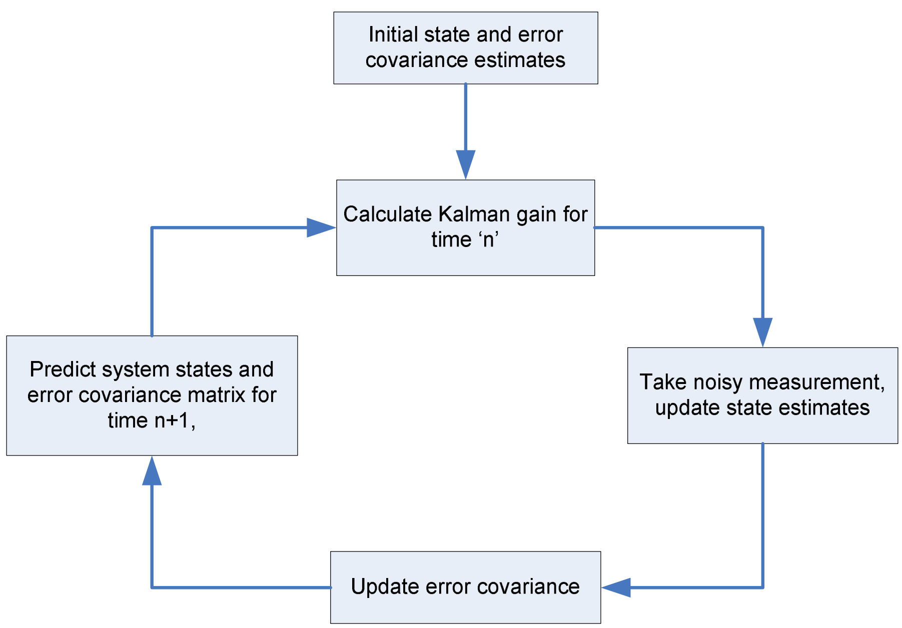


KALMAN FILTER

The Kalman filter is an optimal linear state estimator capable of providing estimates of a dynamic system's states using only noisy measurements and the state of the system at the previous instant. It can be used to estimate a system state in the future, or refine previous measurements to account for noise. In this project, a 16-state Kalman filter will provide corrections to the intertial sensors. Each error state will consist of a Gauss-Markov model for the error source; that is, the state will be zero mean and dependent only on the error state at the previous time instance.

Three types of filters will be used for this project: the original, Extended, and Unscented Kalman Filters. The original filter, though an optimal estimator, is only capable of being applied to linear systems. The filter must be modified to handle a non-linear system. The Extended Kalman Filter does not require that the system model be consisted of linear functions; rather, the less stringent requirement that the system be constructed of differentiable functions is sufficient. However, the Extended Kalman Filter can be highly computationally intensive as it requires the Jacobian of a matrix to be calculated for both the state transition and observation matrix. The Unscented Kalman Filter, however, does not require this linearization technique, and thus does not increase computational cost as dramatically as the EKF.

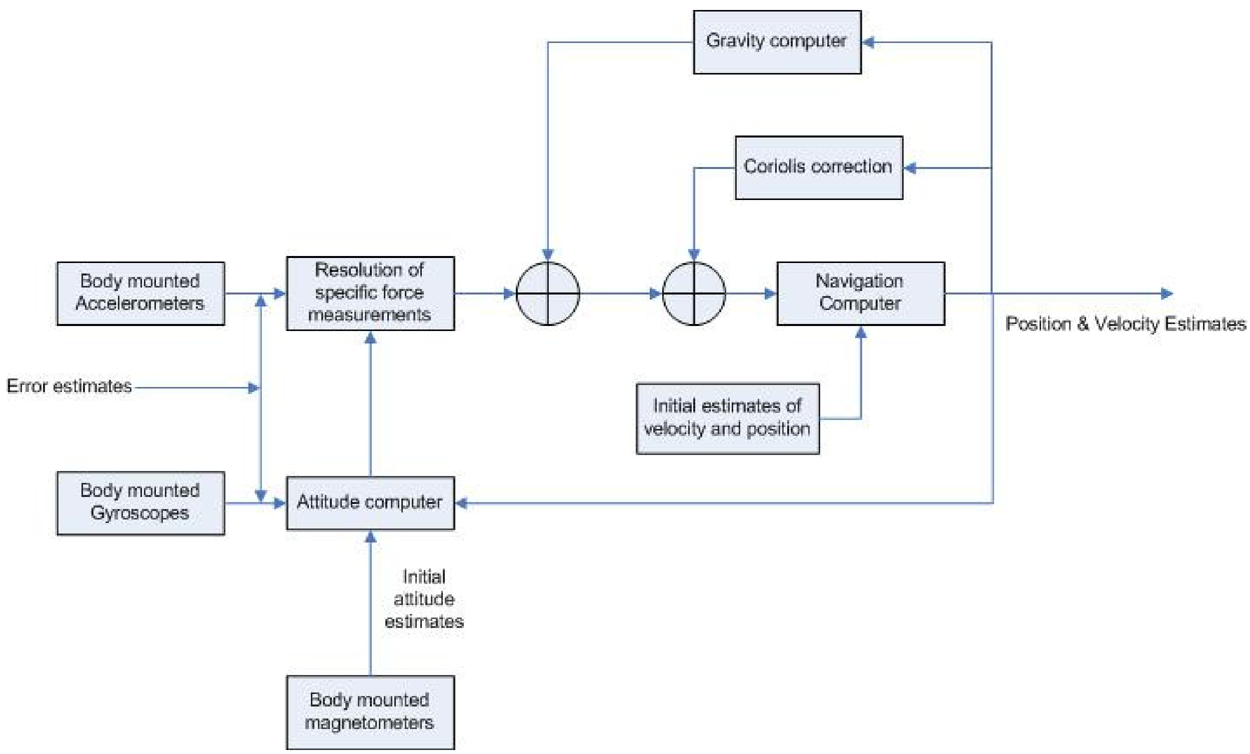
FIGURE 2: KALMAN FILTER BLOCK DIAGRAM



STRAPDOWN SOLUTION

Inertial navigation is performed by initializing to the absolute position of the vehicle and using relative inertial measurements to update the position as the vehicle moves. Traditionally inertial navigation has been implemented in a so-called stationary-platform system in which the IMU is mechanically isolated from the vehicle in order to maintain unchanging axial headings. The project will use a strapdown navigation system shown in Figure 3. In a strapdown system the IMU is rigidly attached to the vehicle so it undergoes all of the same forces and rotations as the body [4]. An initial attitude is established by magnetometers, and relative rotations thereafter are measured by gyroscopes. As the IMU rotates its true axis directions change, so the rotational measurements are used to place the accelerometer measurements back in the original frame of reference. Once the initial computations have been completed a closed loop control system corrects for Coriolis and gravity offsets while estimating position and velocity.

FIGURE 3: STRAPDOWN SOLUTION BLOCK DIAGRAM [4]



EQUIPMENT LIST

FIGURE 4: EQUIPMENT LIST

Item	Description
VectorNav VN-100 Evaluation Kit	Inertial Measurement Unit
uBlox EVK-5T	GPS Unit
Custom Mounting Platform	

VECTORNAV VN-100

The VN-100 evaluation kit provides the system with all acceleration, angular rate, and magnetic measurements. The VN-100 was chosen for its respectable performance specifications and a complete software library used to interface the sensor to the Matlab. The VN-100 connects to the PC using a USB cable and it also provides RS232 output for embedded applications.

UBLOX EVK-5T

For the tightly-coupled system to function properly the low-level GPS psuedoranges must be acessed. This data is generally not available on consumer-level GPS recievers, which traditionally output only NMEA strings containing position and velocity information. The EVK-5T allows access to the GPS psuedoranges, as well as providing a suite of data visualization tools.

CUSTOM MOUNTING PLATFORM

For the strapdown solution to function properly the exact distances and angles between the GPS and the IMU must be known to compensate for what is known as the "lever arm effect"(CITE TITERTON HERE). As such, a custom mounting platform must be developed to ensure that the IMU and GPS maintain constant position relative to one another.

PRELIMINARY RESULTS

Thus far, the VN-100 has been successfully integrated with Matlab. Acceleration and angular rate data is capable of being logged and post processed, although the strapdown solution and the Kalman filter have not yet been implemented. Figure 5, below, shows a sample data set from the X-axis accelerometer of the VN-100. For this data set, the VN-100 was tared and kept stationary while Matlab logged the accelerometer values. There is clearly a bias value for this accelerometer as the mean is not zero; also note that the random walk is visible. Identical data sets were logged for the Y and Z axis accelerometer. Matlab was then used to numerically integrate this data twice to provide position plots, seen in Figure 6. It takes only 21 seconds for the Euclidian distance of the sensor to drift 50 meters from the origin.

For preliminary filtering the bias for each accelerometer was calculated by finding its mean value over a 60 second period. This mean was then subtracted from the respective accelerometer channels, and position was recalculated. This plot is below as Figure 7. With this form of bias compensation, it now takes 138 seconds, or 2 minutes and 18 seconds, for the position to drift 50 meters from the origin. It should be noted that this drift varies significantly from data set to data set, sometimes taking over 5 minutes to drift beyond 50 meters, other times taking only one minute. Thus, the tightly-coupled system will be crucial to the performance of this project.

FIGURE 5: ACCELEROMETER DATA

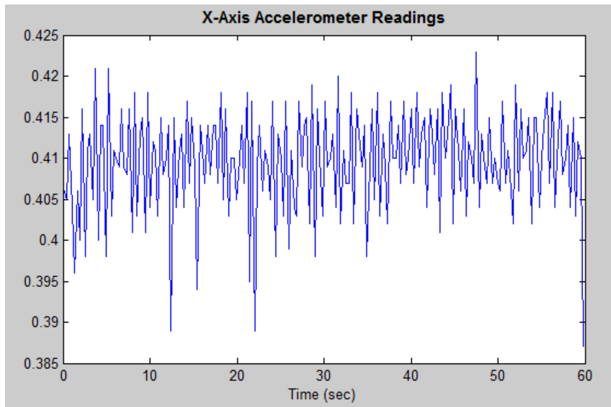


FIGURE 6: IMU POSITION DRIFT

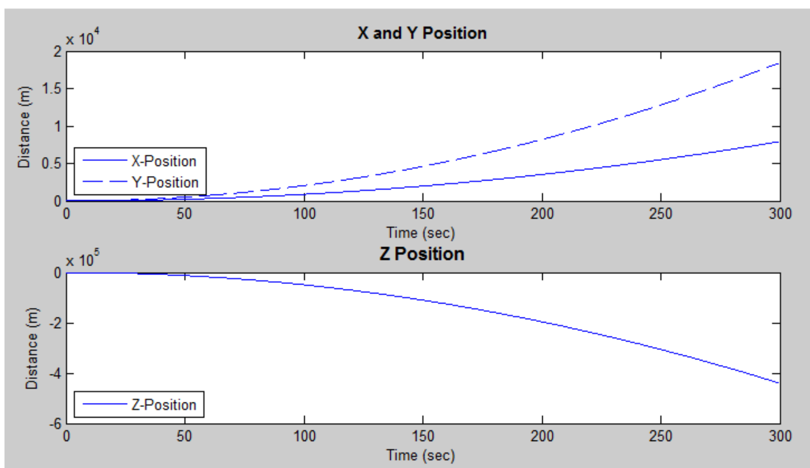
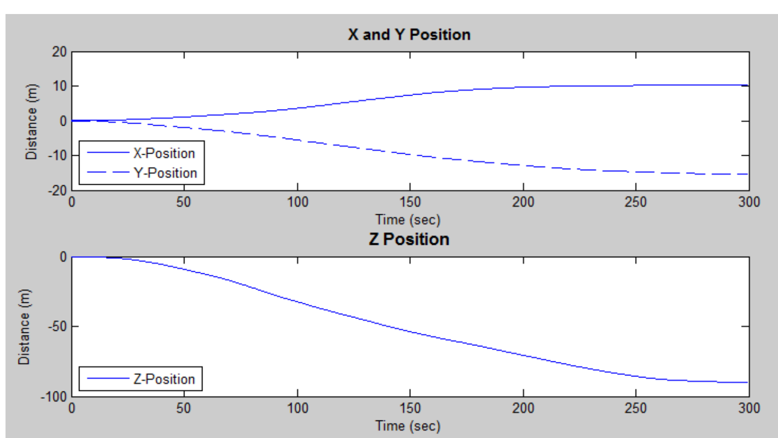


FIGURE 7: POSITION DRIFT WITH ACCELEROMETER BIAS REMOVED



FUNCTIONAL SPECIFICATIONS

FIGURE 8: SPECIFICATION CHART

Deliverable	Specification
Position Drift (No GPS)	<50m in 1.5 minutes
Position Accuracy with GPS Fix	<2m
Initialization Time	60 seconds
GPS Update Frequency	2 Hz
IMU Update Frequency	20 Hz
Kalman Filter	16 Gauss-Markov States

POSITION DRIFT

Once a GPS signal is lost the IMU drift will begin to effect the position information. 50m was chosen as the maximum useable distance drift for pedestrian applications. For autonomous navigation, surveying, or other applications where highly accurate positioning is necessary, this time will be significantly lower. From Figure 7, with a stationary sensor that has had biases removed it took 2 minutes and 18 seconds to drift 50m from the origin. However, when the sensor is in motion it is likely that the accelerometer bias will not be removed completely. Therefore, SINAPS aims to keep distance within 50m for roughly one and a half minutes after the loss of GPS.

POSITION ACCURACY WITH GPS FIX

The EVK-5T provides accuracy of 2m with Satellite Based Augmentation System (SBAS) enabled. Therefore, our system will exhibit position accuracies of at least 2m when a full GPS signal is available.

INITILIZATION TIME

The EVK-5T GPS specifies a time-to-first-fix of 29s, giving a lower bound for initialization time. While the satellites are being located by the GPS, the strapdown solution will also initialize itself to the vehicles initial attitude.

GPS UPDATE FREQUENCY

The EVK-5T GPS is capable of 2 Hz updates. This is the frequency at which we will use the sensor.

IMU UPDATE FREQUENCY

The VN-100 is capable of outputting data at a maximum of 200 Hz. However, the IMU will be sampled at 20 Hz, as early tests have shown that Matlab can have difficulty logging the accelerometer and gyroscope data at frequencies greater than 30 Hz.

KALMAN FILTER

The Kalman filter will consist of 16 Gauss-Markov error states:

- 3 Accelerometer bias States
- 3 Velocity states
- 3 Position states
- 3 Gyroscope bias states
- 4 Quaternion states

The filter will be implemented entirely in Matlab, using modular and vectorized coding methods to ensure the system is robust and optimized for use within Matlab.

SCHEDULE

Figure 9 details the tentative schedule for the spring semester. Dan Monroe will handle the GPS and Strapdown tasks, while Luke Pfister will be responsible for the IMU and Kalman filter. Once the initial system has been integrated, both students will work together on learning and implementing two additional forms of Kalman filtering, Extended and Unscented.

FIGURE 9: SPRING SEMESTER SCHEDULE

Week of:	Luke	Dan
Break	Test IMU, Get Performance Specs, Purchase GPS, Interface with Matlab	
1/25/10	Mounting Platform Design/Construction	Test GPS, Interface with Matlab
2/1/10	Read Unfiltered Gyro Data	Program Strapdown Solution/Conversion
2/8/10	Model Error States	Initial Heading Determination (Wahaba)
2/15/10	Integrate and Test Complete System, Get Performance Specs	
2/22/10	Extended Kalman Filter Research	
3/1/10	Program Extended Kalman Filter	
3/8/10	Integrate and Test Complete System, Get Performance Specs	
3/15/10	Extended Kalman Filter Research	
3/22/10	Program Extended Kalman Filter	
3/29/10	Integrate and Test Complete System, Get Performance Specs	
4/5/10	Comparison of All Three Systems	
4/12/10		
4/19/10		
4/26/10	Wrap Up: Final Report, Presentation	

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