Integration of GPS and MEMS inertial sensor

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Abstract

Recent technological advances in both Global Positioning System (GPS) and low cost MEMS based inertial sensors enabled monitoring the location of moving platforms for numerous positioning and navigation applications. When miniaturized inside any moving platforms, MEMS based inertial navigation system (INS) can be incorporated with GPS and enhance the performance in denied GPS environments (like in urban canyons). GPS/INS integration is motivated by the complementary characteristics of the two systems: INS slow drifts are compensated by GPS long term accuracy whereas INS can coast during GPS outages. The coupling between GPS and INS is classically performed by means of a hybridization filter that fuses information from both navigation systems to compute the correct data’s. The integration helps to limit the INS derived Position, Velocity and Attitude errors by using GPS measurements as update to the position and velocity whenever it is available. The combination of the two systems, traditionally performed by Kalman filtering (KF), but KF has limited capabilities in providing accurate positioning especially when the system is highly non-linear and the noise is Non-Gaussian. Particle filtering (PF) was suggested to accommodate for arbitrary inertial sensor characteristics, motion dynamics and noise distributions. Particle filters (PFs) are good candidates to solve the estimation problem associated to INS/GPS hybridization, because of the nonlinear measurement equation. PFs belong to the class of Sequential Monte Carlo methods, which provide a set of powerful algorithms for handling the nonlinear and non-Gaussian state space models.
Aircraft Navigation Systems

- Determination of position of an aircraft is a challenging task in Aerospace field.
- In the beginning of aircraft history mechanical system is used to find the position of an aircraft.
- Nowadays mechanical systems is replaced by electronics systems (Avionics Systems) like GPS, INS, etc..
- The purpose of this replacement is provide the accrued information, secure and safe flight.
Disadvantages in Navigation systems (GPS, INS)

- Low data rate
- Susceptible to Jamming
- Unbound errors as time increases
- High cost for the quality
Solution technique (GPS/INS)

- For an aircraft or other autonomous vehicles, navigation is most important one. Various systems are used in navigation of aircraft, like inertial navigation systems (INS), global positioning systems (GPS), air-data dead reckoning systems, Radio Navigation Systems (RNS), Doppler heading reference systems, etc.

- Our interest lies in integrating any two systems and to find the position of the object with the help of that new modified system, here this project deals with the integration of INS and the GPS to provide the best possible estimate of the aircraft position in terms of the latitude, longitude and height above the surface of the earth.
Project Concept

INS Position

GPS Position

High accurate Position values

Position Error

PF

INS OUTPUT

GPS OUTPUT

Carrier Environment

PF

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Advantages Of GPS/INS Integration

- It autonomous and does not rely on any other external aids or on visibility conditions and maintains the availability of navigation solution during GPS outages due to interference, jamming, etc.
- Optimal mixing of the INS and the GPS information reduces the effect of GPS errors. Therefore GPS-only accuracy is improved on by the integrated solution.
- The INS provides the full navigation (6 degrees of freedom) state without differentiation. The 6 degrees of freedom refer to 3 translational and 3 rotational degrees of freedom. GPS signals could be used to determine accelerations by differentiation or attitude by techniques.
- The INS provides the navigation solution in real time (i.e. without latency) at rates higher than may be achievable from a GPS receiver.
Approach used to solve problem:

- The combination of the two systems, traditionally performed by Kalman filtering (KF), due to the inherent errors of MEMS inertial sensors and the relatively high noise levels associated with their measurements.
- KF has limited capabilities in providing accurate positioning especially when the system is highly non-linear and the noise is Non-Gaussian.
- Particle filtering (PF) was suggested to accommodate for arbitrary inertial sensor characteristics, motion dynamics and noise distributions.
- Particle filters (PFs) are good candidates to solve the estimation problem associated to INS/GPS hybridization, because of the nonlinear measurement equation.
- PFs belong to the class of Sequential Monte Carlo methods, which provide a set of powerful algorithms for handling the nonlinear and non-Gaussian state space.
Particle Filter algorithm

1. Generate initial particle set for aircraft position.
2. Get Measurement
3. Predict Particles (Plant)
4. Update Particle weights using measurement
5. Normalise the weights
6. Re-sample the particles
7. Calculate State (sample mean)
‘Select with Replacement’ Resampling algorithm

1. Assign weight to every particle.
2. Normalise the weights.
3. Calculate the cumulative sum of all particles.
4. Generate a sequence of random numbers. Sort them in ascending order.
5. If the number is less than cumulative sum for a particle, increase the count for number of copies of that particle. Otherwise, take the next particle cumulative sum.
6. If particles are over?
   - If yes, final state estimate.
   - If no, take the next particle cumulative sum.
7. Repeat until all particles have been selected.

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Block diagram of INS/GPS integration

- INS
  - Position
  - Velocity
  - Attitude

- GPS
  - Position
  - Velocity

- Sensor Biases Corrections

- Particle Estimation for Prediction (include INS Mechanization)
  - PF Update using Particle Estimation

- P
- V
- A

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**Inputs**

In this case technical explanation input of the importance for Particle Filter in the field of moving object tracking and to calculate the RMS Error value, Probability distribute function, Path Prediction are done with help of the below assumption,

- Initial State \([X] = 0.1\);
- Velocity \([v] = 25 \text{ m/s}\);
- Process Noise Covariance \([Q] = 0.001\);
- Measurement Noise Covariance \([R] = 0.1\);
- Simulation Length \([t_f] = 75\);
- Dimension of the state vector \([d] = 0.1\);
- Time step value \([t] = 75\);
- Number of Particles \([N] = 100\).
Results
Probability Distribution Function prediction by PF
Moving object Position prediction by PF
RMS Horizontal Error Estimation

Loosely Coupled GPS/INS Integration Performances

RMS Horizontal Error [meter]

Time [hr]

0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2

- Dotted line: GPS
- Dash-dotted line: INS
- Solid line: GPS/INS
Error Estimation by Particle Filter

![Error Estimation Graph](chart.png)
Conclusion

- Providing accurate information for the aircraft is the challenging task. The integration of the aircraft systems is a way to attain more accuracy level of information which is relevant to the aircraft, it is a combination of any two systems, and also it is an efficient way to overcome their individual disadvantages, particle filter is a good approach to integrate any two avionics systems with good solution based on the particle selection method. The basic concept involve in the PF integration approach is to select the particles which is nearby the object, after the first iteration process the less weight particles are eliminated from the prediction technique process. Particle filter approach is independent one, which predicts the exact position of the moving object based probability distribution function of the more weight particles. Low accuracy particles (less weight) are eliminated from the calculation, so the more weight particles give the good solution compare to other integrate approach methods.
REFERENCES

THANK YOU