

A Review of Navigation Systems (Integration and Algorithms)

Ahmed M. Hasan, Khairulmizam Samsudin, Abd Rahman Ramli, Raja Syamsul Azmir,
and Salam A. Ismaeel

Department of Computer and Communication System Engineering Universiti Putra Malaysia,
43400 UPM-Serdang, Malaysia

Abstract: Significant developments and technical trends in the area of navigation systems are reviewed. In particular, the integration of the Global Positioning System (GPS) and Inertial Navigation System (INS) has been an important development in modern navigation. The review concentrates also on the analysis, investigation, assessment and performance evaluation of existing integrated navigation systems of accuracy, performance, low cost and all the issues that aid in optimizing their operating efficiency. The integration of GPS and INS has been successfully used in practice during the past decades. However, much of the work has focused on the use of a high accuracy Inertial Measurement Unit (IMU), which is an inertial sensors block without navigation solution output, and hence, this research area is also reviewed in this paper.

Key words: Vehicular navigation, Inertial Navigation System, GPS, Inertial Measurement Unit

INTRODUCTION

The past four decades have seen an exponential increase in the use of inertial technology to satisfy military and civilian air and land navigation requirements. In recent years, there has been an increasing interest in the analytic type of inertial navigation systems mainly due to the advent of fast and relatively low cost microprocessors (Amean, 2001).

Since the early 1960's, modern navigation has been making use of the hybrid (integrated) navigation systems, where various electronic sensing devices (sensors) are used side by side, to collect the information necessary to find the "continuous" position of the navigated vehicle, and to reduce inertial sensor errors (Ismaeel, 2003).

The integrated system combining several independent navigation sensors, like inertial measurement unit, Doppler radar, and radio position fixed devices (e.g. TACAN) were used. Sindlinger (1978) investigated the optimization of such integrated navigation systems e.g. a "Combined Navigation System".

The basic objective of the following literature survey is to look at research activities in the field of GPS, INS and integrated GPS/INS navigation systems and their applications.

Inertial Navigation System (INS):

An increasing demand for small-sized and low-cost inertial navigation systems (INSs) for use in many applications such as personal navigation, car-navigation, unmanned aerial vehicles (UAVs) and general aviation. Advances in fiber optic gyroscope (FOG) and micro-electro-mechanical systems (MEMS) technologies have shown promising signs toward the development of such systems. Compared to higher-grade systems, a low-cost INS can experience large position and attitude errors over short time intervals. This is mainly due to large uncertainties in the sensor output and therefore INSs built on these sensors are vulnerable to nonlinear error behavior, especially when the attitude errors become very large (Shin, 2001).

If the accuracy of a low-cost INS can be improved, cost can be reduced in existing applications and new applications can emerge. As most of the uncertainties exist in the sensor error behavior, calibration would improve the accuracy significantly. However, intensive calibration would increase the cost significantly. Choosing an appropriate estimation method is a key problem in developing the INS system. In the following literature review, many researchers attempt to increase the INS sensor accuracy.

Corresponding Author: Ahmed M. Hasan, Department of Computer and Communication System Engineering
Universiti Putra Malaysia, 43400 UPM-Serdang, Malaysia
E-mail: ahmedmudher@yahoo.com, {kmb, arr, rsa} @ eng.upm.edu.my
with gs20491@mutiara.upm.edu.my

Shin (2001) used a new field calibration method, which was developed and tested successfully. This method does not require aligning the IMU to the local level frame. Furthermore, the bias estimation of the calibration method was not affected by the reference gravity error. Almost half of the positioning error could be removed with the accelerometer calibration information. All attitude components converged within three minutes with Root Mean Square 0.030 non-holonomic constraints which dramatically reduced the horizontal positioning error, within 40 m for a 20 minutes operation. Therefore, low cost INSs can be used as a stand-alone positioning system during the GPS outages of over 10 minutes. While Nassar (2003) used different stochastic processes for modeling SDINS sensor errors. The actual behavior of SDINS sensor random errors was investigated by computing the autocorrelation sequence using long data records. Autoregressive processes were introduced as an alternative approach in modeling SDINS sensor residual biases. Different methods for the optimal determination of the Autoregressive model parameters were studied; the results showed that the implementation of Autoregressive models improves the results by 40% - 60% in SDINS stand-alone positioning and by 15% - 35% in SDINS/DGPS applications during DGPS outages. Also, a novel method of using vehicle dynamic information in de-noising raw INS sensor noises is investigated by Ding and Wang (2007). Vehicle dynamics can constitute additional observation information to be used for improving the integration performance. Since vehicle dynamic model has a low pass filter characteristics, passing the raw INS sensor measurements through it would effectively reduce the high frequency noises. This filtering processing has been implemented using kalman filter. By comparing this method with existing de-noising methods, the parameters of the proposed method have physical meaning and can be directly evaluated from existing trajectory data sets. Also, the cumulative knowledge of the vehicle dynamics can contribute to the improvements of de-noising performance.

A highly accurate attitude determination algorithm was presented by Lichun *et al* (2001) in which aircraft's inherent kinetic property is predicted by a linear-two-point polynomial predictor and combined with a short term highly accurate INS. On the other hand, aircraft's inertial motion is predicted using a quadratic-five-point predictor and is combined with the long-term accuracy of GPS. Linear, convex combination of linear-two-point and quadratic five-point predictors is done and the test results show that the INS attitude accuracy is improved by using updates from determined attitude of the GPS.

Kevin *et al* (2003) discussed the design and implementation of an embedded low cost inertial navigation system (INS) using an inertial measurement unit (IMU), digital compass, GPS, and an embedded computer system. The INS is capable of providing continuous estimates of a vehicle's position and orientation. Typically IMU's are very expensive systems; however this INS will use "low cost" components. Unfortunately with low cost also comes low performance and is the main reason for the inclusion of GPS, compass, and Kalman filtering into the system. Thus the IMU will use accelerometers and gyros to interpolate between the 1Hz GPS positions. All important equations regarding navigation are presented and a discussion of the developed embedded system. Results are presented to show the merit of the work and highlight various aspects of the INS. While Chin *et al* (2005) examined the feasibility of designing an accelerometer-based (or gyroscope-free) inertial navigation system that uses only accelerometer measurements to compute the linear and angular motions of a rigid body. The accelerometer output equation is derived to relate the linear and angular motions of a rigid body relative to a fixed inertial frame. A sufficient condition is given to determine if a configuration of accelerometers is feasible. If the condition is satisfied, the angular and linear motions can be computed separately using two decoupled equations of an input-output dynamical system: a state equation for angular velocity and an output equation for linear acceleration. The effects of accelerometer location and orientation errors are analyzed. Algorithms that identify and compensate these errors are developed.

Global Positioning System (GPS):

The Global Positioning System or GPS has been developed for the purpose of enabling accurate positioning and navigation anywhere on or near the surface of the earth. In addition to the US system GPS-NAVSTAR, the Russian GLONASS system is also in place and operational. Other such systems are under study. The key measurement involved is the time of travel of signals from a particular GPS spacecraft to the navigation receiver. Navigation accuracies of the order of tenth of meters are achievable, and accuracies at the centimeter level can also be obtained with special enhancement techniques.

In recent years spacecraft have already been exploring the use of GPS for in-orbit navigation. As the receiver is solid state, rugged, power-lean, and cheap, GPS for autonomous navigation will be an objective even for low-cost spacecraft of only modest sophistication. The following literature survey focuses on developing GPS as a stand-alone Global Navigation System.

Sato *et al* (2000) described the improvement of the positioning accuracy of a GPS receiver, using software to apply the GPS to compact, hand-held devices. DGPS with a software FM demodulator, and a modified Kalman filter are proposed and applied to a GPS receiver. The positioning accuracy is, 35 m with a standalone GPS, 9 m with DGPS and 15 m with a Kalman filter. With both methods, the positioning accuracy is drastically improved to 2 m. while Kralli *et al* (2000) reduced the GPS error by reinvestigated the measurement model associated with Global Positioning System (GPS) signal processing. It was argued that the GPS positioning model is better formulated as a linear equation with errors in both the data matrix and measurement variables. Furthermore, depending on the nature of the measurement errors, the model is categorized into unstructured and structured perturbation cases. In the former, the total least squares method is proposed for position fixing and clock bias determination. In the latter, an iteration method is developed to search for the optimal solution. In addition to the position update, both the total least squares and optimization methods provide estimates of the model mismatch which leads to a measure of GPS receiver autonomous integrity monitoring. There are two new GPS fault detection metrics. The first integrity test statistic is the norm of the residual vector in the total least squares estimate. Statistical properties of this test statistic are obtained for integrity monitoring. The second metric is a two-dimensional vector that characterizes the norm of the residual vector and mismatch matrix, both are outcomes of the total least squares method or the optimization method. The positioning and integrity monitoring schemes are verified using simulated examples. Also, Mladen *et al* (2006) developed a simple statistical model of positioning error estimation and applied on data obtained by measurements in order to verify the findings. The method, which needs only position information without satellite constellation, provides sufficient accuracy when simultaneously gathered plain GPS and DGPS data are compared. From the results obtained by the measurements, they proved that the position accuracy for the low-cost DGPS is consistently better than that of plain GPS. Two different off-the-shelf models of GPS receivers were used as a source of DGPS corrections during that period of time, producing similar accuracy of the DGPS

Calibration of different models used for pedestrian navigation presented by Q. Ladetto *et al* (2001). Where, information on traveled distance and azimuth sensed by inertial sensors is merged with GPS observation through Kalman filtering. All models use GPS positions without differential corrections to calibrate systematic errors present in inertial sensors. Also, different prototypes had been developed. They integrate a digital magnetic compass or gyroscopes, tri- or bi-axial accelerometers, an altimeter and a mono-frequency GPS receiver. And show that an integrated system improves the reliability and precision of the trajectory, as compared with GPS only. But Xuchu *et al* (2000) developed UKF to model position and velocity estimation for nonlinear filtering. The model is nonlinear and has variable measurement number far coping with an arbitrary number of satellites. The model is investigated applying it to unscented Kalman filter for position estimation. The motivation of this research is to address the GPS positioning problems in vehicle navigation under had circumstances where the visible satellites are variable frequently or less than four. Comparison shows that this approach provides better estimation than other solutions.

Jahn (2001) presented a wideband Land Mobile Satellite (LMS) channel model using discrete tap delay lines with an exponential decay $Ph(\tau)$ versus delay time .

Adopting this idea, Boulton *et al* (2002) proposed a multipath model for the Spirent simulator. To study the characteristics of the LMS navigation multipath channel in urban, suburban and rural environments, Steingass and Lehner (2003) simulated satellite signals using an airship. By analysing the delay characteristics of the directed and reflected signals transmitted from the airship, it was found that the channel had a "strong elevation dependency". While Multipath effects on GPS code measurements under indoor conditions were studied by Lachapelle *et al* (2004). The result showed that, under attenuated signal conditions, multipath is large and, in indoor situations, the direct signals are not available which can lead to large reflected signals. The classical multipath rejection techniques developed for line-of-sight signals. Also, Pérez-Fontán *et al* (2004) analyzed the experimental data for the satellite-to-indoor channel using a helicopter to simulate the satellite. The details of the environments, such as internal walls, external walls, doors and windows were considered as the factors to produce the reflected and diffracted signals

Ma *et al* (2001) and Klukas *et al* (2003) utilized an Urban Three-State Fade Model (UTSFM) to describe the GPS signal fading distribution according to satellite elevation angles, based on the analysis of signal power fading measurements gathered over a few hours in several different environments. UTSFM is composed of three types of probability density functions: Rician, Rayleigh and Loo, which respectively describe three types of signals: line-of-sight (LOS) signal and multipath signals, multipath signals only, and attenuated LOS signal and multipath signals. The empirical and UTSFM fading matched well in urban canyon, suburban, road side and open sky environments. In the other hand, Watson (2005) presented an overall introduction of GPS L1

signal propagation mechanisms for indoor channel modeling. He utilized high-sensitivity techniques to characterize fading and multipath characteristics in two indoor environments. By analyzing the signal characteristics of signal power, positioning performance, Doppler error and phase change, he summarized GPS-indoor channel properties. Based on these GPS-indoor channel properties, a novel GPS-indoor channel model was introduced for specific indoor environments.

Hyung *et al* (2003) introduced an integration method of Global Positioning System (GPS) pseudoranges and Time Difference of Arrival (TDOA) measurements from a pilot signal of a wireless communication network to solve the navigation problem in the case that the number of visible GPS satellites is not sufficient. TDOA measurements are known to have poor accuracy due to technical limitations of a communication system and propagation environments. The major error source of TDOA is the Non-Line-of-Sight (NLOS). To estimate the TDOA error in a cellular network, we propose a method using a Kalman filter for each TDOA channel. In addition, a method to measure TDOA error is proposed. Some simulations and real tests are conducted to evaluate the performance of the proposed methods. Test results show that the proposed methods continuously provide subscribers a reasonably accurate location in the case that GPS data are occasionally insufficient.

Ou. *et al* (2005) estimated the Hurst parameter of GPS clock difference data based upon the wavelet transform. When $0 < H < 1$, the GPS clock difference data is taken for as a Gaussian zero-mean nonstationary stochastic process which can be considered having the $1/f$ fractal characteristics, During the course of the estimation of the GPS common-view data with the multi scale kalman bank, they process the single-channel and multi-channel common-view observation data, respectively. This proposed algorithm gives a new method for estimate the time series data.

A feasibility study for the development of a Neural Network (NN) based model for the prediction of South African GPS derived total electron content (TEC) is presented by John *et al* (2007). Three south African locations were identified and used in the development of an input space and NN architecture for the model. The input space included the day number (seasonal variation), hour (diurnal variation), sunspot number (measure of the solar activity), and magnetic index (measure of the magnetic activity). An analysis was done by comparing predicted NN TEC with TEC values from the IRI-2001 version of the international Reference Ionosphere (IRI), validating GPS TEC with ionosonde TEC (ITEC) and assessing the performance of the NN model during equinoxes and solstices. The results show that NNs are indeed very suitable for predicting the GPS TEC values at locations with South Africa.

Genetic algorithms (GA) are general-purpose search procedures, optimization methods, or learning mechanisms based on Darwinian principles of biological evolution. When provided with a suitable objective function that evaluates the performance of the control systems, using genetic algorithms can readily optimize navigation parameters for more accurate navigation solutions. Chih *et al* (2007) rephrased the transformation of coordinates from global positioning system (GPS) signals to 2-D coordinates as a regression problem that derives target coordinates from the inputs of GPS signals directly; a Genetic-based solution is proposed and implemented by the techniques of symbolic regression and genetic programming. In this paper the computational costs and inaccuracy can be reduced, because coordinates for a GPS application are obtained by using simpler transformation formulas. The proposed method, although it doesn't exclude systematic errors due to the imperfection on defining the reference ellipsoid and the reliability of GPS receivers, effectively reduces statistical errors when accurate Cartesian coordinates are known from independent sources. Finally, from the results it seems that the proposed method can serve as a direct and feasible solution to the transformation of GPS coordinates.

Although Kalman filter is used widely in GPS/INS integration. Mao *et al* (2007) proposed an extended kalman filter approach to estimate the location of a unmanned aerial vehicles (UAV) when its GPS connection is lost, using inter-UAV distance measurements. The results from a recent trial conducted by DSTO in Australia with three UAVs are presented. It is shown that the location of a maneuvering UAV that has lost the GPS signal can be determined to an accuracy of within 40m of its true location simply by measuring the range to two other UAVs at known location, where the range measurement error has a zero mean and a standard deviation of 10m. The proposed method may solve the practical problem that during a flight, a UAV may temporarily lose its GPS connection for a rather long time period.

Li Y. and Xi X. (2007) discussed the method of combining FFT and circular convolution. Since FT acquisition method is usually adopted in high dynamic GPS receiver because of its faster process speed than circular convolution. But FFT acquisition spent more time to get GPS signal in order to reach the higher requirement of position precision, when the carrier has larger dynamic range. Computational burden of this method is very little than other two methods. This new method can reduce the cost time of acquisition so this method can be widely used in high dynamic situation and high requirement of positions precision.

Dan *et al* (2007) proposed two stage GPS anti-jamming processor based on adaptive arrays. Firstly, the array received signals are projected onto the orthogonal subspace corresponding to interference to suppress interferences. Then the interference free signals are further processed by a conventional data-independent beamforming to enhance the GPS direct-path signal and mitigate GPS multipath signals. Simulation results demonstrate the performance of the proposed algorithm.

Mohammad *et al* (2007) compared the performance of two popular coarse-acquisition (C/A) $C = No$ algorithms the first algorithm is variance summing method (VSM), and the power ratio method (PRM), in terms of their estimates in 1) additive white Gaussian noise (AWGN), 2) narrowband continuous wave interference (CWI), 3) their response to quantization and saturation effects, and their 4) dynamic range.

The algorithms were implemented as a part of a software receiver. Two L1 GPS data sets are examined; one was obtained from a GPS raw data collection setup, while the other was obtained from a GPS signal simulator. The collected set was stored with almost constant $C = No$ level while the simulated one contained variable $C = No$ levels. The effect of adding AWGN on the $C = No$ estimate was directly proportional with the noise power. The $C = No$ estimates suffered more when the CWI frequency was closer to the IF of the receiver. The PRM suffered from saturation at higher $C = No$ levels. The VSM showed good tracking at high $C = No$ levels and better immunity to limited quantization levels, while its $C = No$ estimate suffered from rapid fluctuations in power levels when sudden power steps occurred.

Daniel *et al* (2007) presented a methodology to evaluate the position availability of automotive grade global positioning system (GPS) receivers intended for Telematics applications utilizing a multichannel GPS satellite signal simulator in a controlled laboratory environment. Initially, field testing of two distinct GPS receivers was conducted in an urban canyon environment and a foliage environment to assess each receiver's position availability performance. Test scenarios were then developed on a multichannel GPS satellite signal simulator in order to create controlled and repeatable stimuli to the GPS receivers. The scenarios take into account the actual satellite constellations at the same day, time, and locations of the field data collections. Furthermore, the number of visible satellites and power levels was adjusted in order to stimulate the hardware tracking sensitivity, hardware acquisition sensitivity, dynamic range, and navigation filter design, all of which impact position availability for GPS receivers. Quantitative results demonstrated good correlation between the results obtained using the developed test scenarios and the results from the field testing. The proposed methodology will result in reducing validation cost and time to market for automotive Telematics products.

A possibility to obtain a new time reference constantly locked to the Caesium derived GPS satellites carriers was investigated by Caciotta *et al* (2007) using means of a new GPS receiver architecture able to lock the two GPS carriers and mix them to obtain a reference frequency with an accuracy close to the GPS one. This is very important in Perceived Power Quality distributed measurements systems where the exact knowledge of the events on the geographic compass is strongly joined to the capability to associate them an accurate time. A simulation of the carrier tracking loop has been performed. It shows how choosing appropriately the frequency of the low-pass filter of Costas loop, a modified PLL typically used in GPS system, it is possible to recover carriers in presence of high noise to signal ratio too. The front-end of the system able to select GPS frequencies, which is the first block of the entire system, was also realized. The simulation of the L1 carrier tracking block showed the possibility to obtain a 1575.42 MHz reference with a standard deviation of approximately 10 Hz. Similar performances are expected also for the L2 tracking loop.

David M. and Bradford P. (2007) developed a cascaded estimation algorithm for estimating all of the biases and states for full state feedback and dead reckoning of a farm tractor through short global positioning system (GPS) outages. First, a conventional (one stage) estimation scheme is presented. The single state estimation scheme is shown to have degraded performance in bias state estimation and dead-reckoning due to vehicle model errors. However, the states for position and velocity are not highly coupled to the tractor dynamic states, allowing for separation of the estimators. Therefore, the state estimation algorithms are divided into two cascaded estimators in order to prevent the errors in the vehicle model from corrupting the navigation states. A dead reckoning (or navigation) estimator estimates the entire inertial sensor biases while GPS is available. When GPS is not available, the dead reckoning estimator integrates rate measurements to provide position and heading estimates in order to maintain continuous control of the vehicle through these GPS outages. A second estimator is then used to estimate the additional states needed for full state feedback control algorithms. Bias estimates from the dead reckoning estimator are used to correct the sensor measurement used in the second estimator. An extended kalman filter (EKF) is utilized for each of the estimators. Results are given, showing that the cascaded estimation technique provides better estimation of the vehicle states over a conventional estimation scheme, especially during a GPS outage. Results are also given which verify the ability of the estimation algorithm to estimate all of the system biases and provide continuous control of the tractor through a short GPS outage.

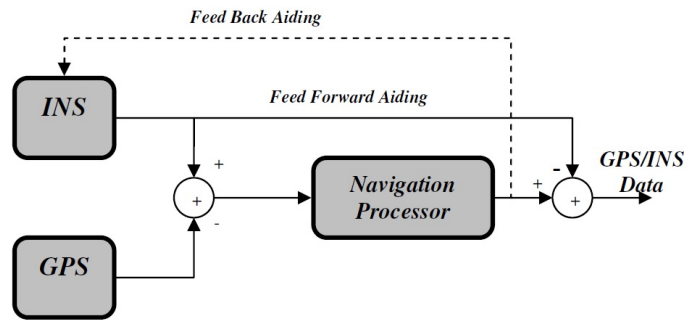


Fig. 1: Inertial aiding concept.

GPS/INS Integration:

Integration of GPS with an inertial Navigation System improves the quality and integrity of each navigation system: use of GPS permits calibration of inertial instrument biases, and the INS can be used to improve the tracking and re-acquisition performance of the GPS receiver. There are two error calibration techniques that can be implemented in an integrated GPS/INS system: the feedforward (or open loop) method and the feedback (or closed loop) method as shown in figure (1).

Also, there are two basic types of methods for integration of GPS and INS data in a system. These are loosely coupled and tightly coupled. With a loosely coupled integration (Sung, 2002). A navigation processor inside the GPS receiver calculates position and velocity using GPS observables only. An external navigation filter computes position, velocity and attitude from the raw inertial sensor measurements and uses the GPS position and velocity to calibrate INS errors.

A benefit of a loosely coupled system shown in figure (2) is that the GPS receiver can be treated as a "black box." The blended navigation filter is simpler if using GPS pre-processed position and velocity measurements. However, if there is a GPS outage, the GPS stops providing processed measurements and the inertial sensor calibration from the GPS/INS filter stops as well.

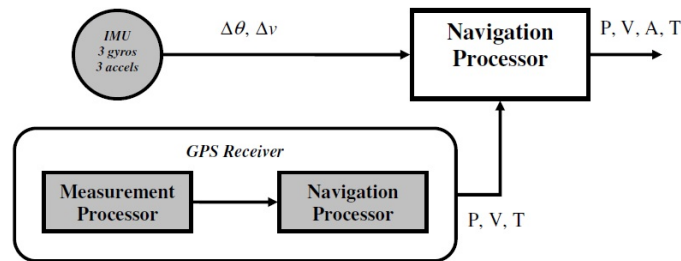


Fig. 2: Loosely Coupled GPS/INS Integration.

A more complicated GPS/INS filter design limits the problems due to GPS satellite block-age; figure (3) shows a tightly coupled GPS/INS integration. In this system, the external navigation filter receives raw GPS measurements of pseudo-range and Doppler or delta-range. The tightly coupled GPS/INS filter benefits from GPS measurement updates even if there are less than four satellites available for a complete GPS navigation solution.

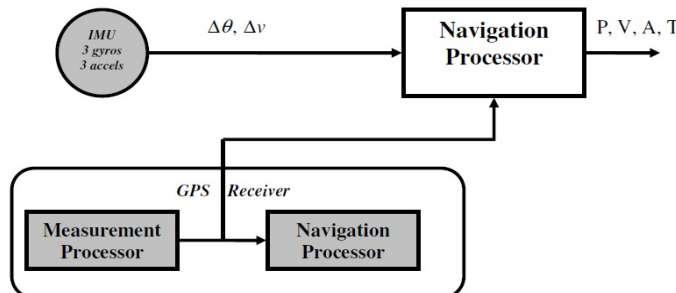


Fig. 3: Tightly Coupled GPS/INS Integration.

Figure (2) and figure (3) illustrate two common methods of GPS/INS integration in the category of GPS aiding of INS. Figure (4) shows a method of INS aiding of GPS: ultra-tightly coupled or deep integration.

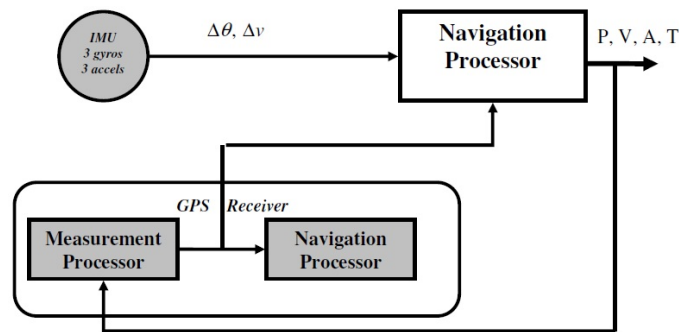


Fig. 4: Ultra-Tightly Coupled or Deeply Integrated GPS/INS system.

An INS can aid a GPS receiver on a variety of different levels. INS outputs of position, velocity and attitude, used as external inputs to a GPS receiver, aid in pre-positioning calculations for faster signal acquisition and in interference rejection during signal tracking.

Navigation is a typical field of nonlinear dynamic systems and in the core of navigation system development lies the problem of estimating the states of a dynamic system. When it comes to state estimation for nonlinear systems, however, there is no single solution available that clearly outperforms all other strategies. The following literature review concentrate but not limited to these three approaches on estimation methods for integrated navigation systems:

- a The linearized Kalman filter (LKF) or the extended kalman filter (EKF);
- b Sampling-based filters, such as the unscented kalman filter (UKF) and particle filters; and
- c Artificial intelligence (AI)-based methods, such as artificial neural networks (ANN) or adaptive neural fuzzy information system (ANFIS).

David (1996) used GPS receivers as an aiding system to inertial navigation system (INS), this integration utilize internal kalman filters that model generic INS's and process the basic GPS pseudorange and delta range (range-rate) data to produce an output of inertially-smoothed, GPS-derived position and velocity. These kalman filters model only the basic nine INS errors (position, velocity, and tilt) and do not model any INS gyro or accelerometer errors. It was found that a significant performance improvement could be achieved under conditions of degraded GPS satellite availability by augmenting this type of filter with the six INS gyro and accelerometer bias errors. From the results it can be shown that under degraded satellite conditions, poor performance can occur with the loosely coupled integration, even while the tightly coupled integration is giving good results, and augmenting the internal GPS kalman filter to include the six gyro and accelerometer bias errors decreased the loosely coupled errors to the level of the tightly coupled integration under the degraded satellite conditions, finally for all loosely coupled analyses, it was found that the GPS and INS kalman filters produced similar accuracy levels, whether good or bad. In addition to, Ismaeel (2003) developed a missile flight simulator with strapdown navigator. Two Kalman filter were used the first one was designed for GPS receiver in high dynamic systems to estimate GPS states and compare the filter operations with least square algorithm. The second Kalman filter was used to incorporate information from the accelerometers and gyros at high rates and information from GPS measurements at lower rates. While Jan W. and Gert F.(2004) described an approach to enhance the performance of tightly coupled GPS/INS systems. First, the advantages of tightly coupled systems compared to loosely coupled systems are clarified. Then, it is shown in hardware-in-the-loop tests and in a test drive that processing time differenced carrier phase measurements instead of delta-range measurements results in an increased velocity and attitude accuracy for the tightly coupled system, which is of great importance in the beginning of a time interval with purely inertial navigation, e.g. when GPS is lost due to jamming. A measurement equation is derived allowing to process the time differenced carrier phase measurements in the navigation Kalman filter. Finally, the proposed method is applied to missile navigation systems, where significant vibrations enter the inertial sensor data.

Mayhew (1999) proposed several methods for improving the position estimation capabilities of a system by incorporating other sensor and data technologies, including Kalman filtered inertial navigation systems, rule-based and fuzzy-based sensor fusion techniques, and a unique map-matching algorithm. In addition the

difference in data rate between GPS and INS systems solved by selecting the GPS and INS systems with the same data rate and working on it instead of extrapolate the slower system data as done in our work. Also, Johnson *et al* (2000) used data fusion to combine measurements from GPS and INS, and show two methods to enhance traditional extended Kalman filter for Unmanned Aerial Vehicles (UAV) navigation. One is based on using fuzzy rules to choose parameters of adaptive filter. The other uses inherent parallelism to speed up iterations in Kalman filter computations. Both methods are described briefly and simulation results are presented. In the other hand, Loebis *et al* (2004) proposed an intelligent navigator system, based on the integrated use of the global positioning system (GPS) and several inertial navigation system (INS) sensors, for autonomous underwater vehicle (AUV) applications. A simple kalman filter (SKF) and an extended Kalman filter (EKF) are proposed to be used subsequently to fuse the data from the INS sensors and to integrate them with the GPS data. In this paper fuzzy logic techniques to adapt the initial statistical assumption of both SKF and EKF caused by possible changes in sensor noise characteristics. This adaptive mechanism is necessary where SKF and EKF can only maintain their stability and performance when the algorithms contain the true sensor noise characteristics. Also, to monitor the performance of the SKF and EKF, another fuzzy inference system (FIS) called the fuzzy logic observer (FLO) is used to assign a weight or degree of confidence, number of the interval, and state estimate. The FLO is implemented using two inputs, and the membership functions of these variables were found using a heuristic method that produced a non-symmetrical shape. The using of FLO with SKF and EKF show improvements in the level of error produced by the proposed algorithms as compared to direct measurement from the sensors. Also, the proposed algorithms have detected transient and persistent faults in the sensors.

Cannon (1999) used two GPS antennas mounted on top and under the aircraft fuselage, in order to achieve sub-meter accuracy for the positioning of a CF-188 jet fighter (Canadian version of the F-18) under 360 degree rolls. The two receivers are cross-linked through the use of a common oscillator and the continuous exchange of position, velocity and clock information to accelerate satellite acquisition during rollovers. A gimbaled INS is used to derive the lever arm between the two antennas and to augment GPS during critical roll over periods. The GPS/INS data time synchronization and data logging are performed using a solid-state data logging system developed for this purpose. GPS data is post-processed in differential carrier phase ambiguity float mode, with respect to a reference station within 60 km from the aircraft. A Kalman filter is used to enhance positioning accuracy, especially during periods of losses of carrier phase lock. The analysis of flight tests conducted under various dynamics shows that a positioning accuracy better than one meter is maintained.

A 17-state GPS-INS integration Kalman filter was implemented using an error model by Knight (1999). Several experimental trials were carried out to evaluate the performance of the developed integration system. Integrated system performance was found to be as good as the highly accurate INS, MAPS, used in the trials of the system. Test trajectory was done for 35 minutes and the system was initially aligned for 15 minutes before navigation. Performance degradation was observed when the GPS signal was blocked. In spite of this degradation, much smaller errors were observed than those with the GPS.

An error model developed by Farhan A. and Kenneth J. (2000) to be used for GPS/INS filter mechanization utilizing the extended Kalman filtering technique. Computer simulation study to evaluate the filter performance is presented in the form of design parameter sensitivity plots. Filter convergence issues are addressed and beneficial effect of vehicle maneuvers during the initial phase is established. This study presented should allow optimum selection of filter design parameters. It was observed that the filter states converged in two transition stages. The first transition removes a large proportion of the initial errors. A final position error magnitude of less than 0.5 m was achieved. An accompanying final velocity error of less than 0.03 m/s was also achieved. These errors were within the design specifications.

Faulkner *et al* (2003) described a development programme in which PC/104 computer based loosely coupled system and DSP based navigation processor is used for developing integrated system. Serial link communication operated at higher baud rates and a modular integrated navigation Kalman filter has been used in their prototype system.

A GPS/INS integrated navigation system based on the theory of multi-sensor data fusion is presented by Wang *et al* (2003). Error models for the inertial measurement unit are generated and included in the extended Kalman filter for INS. An improved decentralized Kalman filter is developed to eliminate obvious error of GPS data and reduce the load of calculation. An adaptive federal Kalman filter is used to fuse the data from GPS and INS to provide smoothed and continuous positioning data against the presence of GPS blockages or communication dropouts and the unbounded INS errors growing with time. The results demonstrate that the performance of the adaptive GPS/INS integrated navigation system is better than that of using only GPS or INS as stand alone system.

Park (2004) provided a solution for the availability and unavailability of the satellite signal in a satellite based navigation systems. Also the Micro Electro Mechanical Systems based inertial sensor technology was used and a Kalman filter describe and applied to analyze the performance of a minimum configured GPS/IMU system for vehicle navigation applications.

An algorithm for integration of a tactical-grade IMU with a conventional high performance receiver for open sky areas developed by Salytcheva (2004), with a high sensitivity receiver for downtown canyons. A loosely-coupled integration scheme with estimation algorithms for two GPS environments was implemented: 1) a conventional Kalman filter for INS error estimation 2) use of multiple Kalman filters with fixed and adaptive measurement covariances. In open sky an attitude accuracy of (0.2 – 0.6)° for azimuth and (0.05 – 0.1)° for roll and pitch for data gaps of 30 to 60 s in duration, the system accuracy in position and velocity domains ranges from 5 to 15 m and from 0.2 to 0.6 m/s respectively. In downtown canyons, the accuracies were tested in position only; positional error ranges from 10 to 50 m with occasional outliers reaching 70 m. John *et al* (2005) identified key parameters of a multipath signal, focusing on estimating them accurately in order to mitigate multipath effects. Multiple model adaptive estimation (MMAE) techniques are applied to an inertial navigation system (INS)-coupled GPS receiver, based on a federated (distributed) Kalman filter design, to estimate the desired multipath parameters. The system configuration is one in which a GPS receiver and an INS are integrated together at the level of the in-phase and quadrature phase (I and Q) signals, rather than at the level of pseudo-range signals or navigation solutions. The system model of the MMAE is presented and the elemental Kalman filter design is examined. Different parameter search spaces are examined for accurate multipath parameter identification. The resulting GPS/INS receiver designs are validated through computer simulation of a user receiving signals from GPS satellites with multipath signal interference present. The designed adaptive receiver provides pseudo-range estimates that are corrected for the effects of multipath interference, resulting in an integrated system that performs well with or without multipath interference present. A quadratic EKF approach by adding the second-order derivative information to retain some nonlinearities is proposed by Wei *et al* (2006). Simulation results indicate that the nonlinear terms included in the filtering process have the great influence on the performance of integration, especially in the case that the low quality INS is used in the integrated system. Furthermore, a two-stage cascaded estimation method is used, which circumvents the difficulty of solving nonlinear equations and greatly decreases the computational complexity of the proposed approach, so the quadratic EKF approach proposed in this paper is of great value in practice. Caron *et al* (2006) developed a GPS/IMU multisensor fusion algorithm, taking context into consideration. Contextual variables are introduced to define fuzzy validity domains of each sensor. The algorithm increases the reliability of the position information. A simulation of this algorithm is then made by fusing GPS and IMU data coming from real tests on a land vehicle. Bad data delivered by GPS sensor are detected and rejected using contextual information thus increasing reliability. Moreover, because of a lack of credibility of GPS signal in some cases and because of the drift of the INS, GPS/INS association is not satisfactory at the moment. In order to avoid this problem, they proposed to feed the fusion process based on a multisensor Kalman filter directly with the acceleration provided by the IMU. Moreover, the filter developed here gives the possibility to easily add other sensors in order to achieve performances required.

Bian *et al* (2006) presented a marine INS/GPS adaptive navigation system. GPS with two antenna providing vessel's altitude is selected as the auxiliary system fusing with INS to improve the performance of the hybrid system. A novel innovation-based adaptive estimation adaptive Kalman filtering (IAE-AKF) algorithm is proposed here in, which is based on the maximum likelihood criterion for the proper computation of the filter innovation covariance and hence of the filter gain. The approach is direct and simple without having to establish fuzzy inference rules. After having deduced the proposed IAE-AKF algorithm theoretically in detail, the approach is tested by the simulation based on the system error model of the developed INS/GPS integrated marine navigation system, Simulation results show that the adaptive Kalman filter outperforms the SKF with higher accuracy, robustness and less computation. It is demonstrated that this proposed approach is a valid solution for the unknown changing measurement noise existed in the Kalman filter.

A comparative study of various kalman filter configurations applied to a low-cost inertial navigation system (INS) for an unmanned airship or blimp was made by Johan B. and Steyn W. (2008) the attitude of the airship was determined using micro-electromechanical sensors (MEMS) gyros with feedback from the earth's magnetic field and gravity vectors. MEMS accelerometer measurements were used as a gravity vector, as the dynamic accelerations on an air ship are small compared with the static gravitational acceleration. The velocity and position estimates were updated from a loosely integrated GPS receiver. They suggests two smaller extended kalman filters (EKF) running in sequence. The first KF estimates the attitude of the airship, while the second EKF estimates the velocity and position of the airship. Finally the solution was implemented on an onboard computer to provide real-time navigation estimates.

The performance of an integrated GPS/INS navigation system for the EX-171 Extended Range Guided Munition (ERGM) was evaluated by Ohlmeyer *et al* (2001). This work shows the system navigation accuracies are determined for a set of representative ERGM trajectories that span the engagement envelope. The ability to estimate and compensate large initial system alignment errors and inertial measurement unit (IMU) errors during flight is also evaluated.

Peterson *et al* (1997) reported the results of early experiments to increase the integration time in order to obtain a higher signal-to-noise ratio. This is the principle of high sensitivity which makes signal reception under indoor environments possible. The use of externally generated assistance information provides high sensitivity receivers with improved acquisition times, sensitivity, and accuracy.

Michael K. and Diane A. (1999) described a new development of vehicle avionics suite, including integration of a low-cost, tightly-coupled integrated Inertial Navigation System/Global Positioning System (INS/GPS) to support vehicle guidance, navigation, and control (GN&C). The generic Integrated Mission Guidance & Tracking System (IMGTS), an open architecture, modular system that supports the requirements for various guidance applications and range safety tracking is also presented.

The feasibility of improving airborne GPS/INS integrated navigation using accurate Deflection Of the Vertical (DOV) information is investigated by Dorota A. G. and Wang J. (1998). Based on the available 2×2 DOV grid, tests were run on GPS/INS navigation data, and the result were compared with the corresponding results where the DOV compensation was not used. The test was conducted using the Airborne Integrated Mapping System (AIMSTM), whose positioning component is based on a tightly integrated GPS/INS.

Two issues were investigated by Lee Y. C. and O'Laughlin D. G. (1998). The first issue was how well a tightly coupled GPS/inertial system can detect slowly growing error. The other issue relates to how long the system can coast upon complete loss of GPS signals caused by interference. Using analytic formulas, this paper determines maximum coasting time possible under various scenarios.

Eduardo M. and Hugh D. (1999) described the design of a high integrity navigation system for use in large autonomous mobile vehicles. A frequency domain model of sensor contributions to navigation system performance is used to study the performance of a conventional navigation loop. On the basis of this, a new navigation system structure is introduced which is capable of detecting faults in any combination of navigation sensors. A decentralised architecture is also presented for the fusion of information from different asynchronous sources. An example implementation of these principles is described which employs a twin GPS/inertial navigation system and a millimeter wave radar/encoder navigation loop.

Alexander (2000) described the improvements made to a system for airborne mapping of the gravity field of the Earth. This research was carried out using an airborne gravity system that was based on a SDINS and receivers in the DGPS mode. The system performance was optimized; especially for geodesy and geophysics. Major results include a demonstrated accuracy of 1.5 mGal for a spatial resolution of 2.0 Km and an accuracy of 2.5 mGal for a resolution of 1.4 Km.

Mohammed M. and Klaus S. (2001) developed and test an airborne fully digital multi-sensor system for digital mapping data acquisition. This system acquires two streams of data, georeferencing and imaging data. The navigation data are obtained by integrating an accurate strapdown inertial navigation system with a differential GPS system (DGPS). The imaging data are acquired by two low-cost digital cameras, configured in such a way so as to reduce their geometric limitations. This approach eliminates the need for ground control (GCP) when computing 3D positions of objects that appear in the field of view of the system imaging component. Preliminary results indicate that major applications of such a system in the future are in the field of digital mapping, at scales of 1:5000 and smaller, and in the generation of digital elevation models for engineering applications.

Gillet and Lithopoulos (2001) described the Position and Orientation System for Land Survey (POS/LS) that Applanix is developing for land survey applications. They show that, a GPS aided INS provides a navigation solution that inherits the best characteristics of both sensors.

Bridging GPS outages for tens of seconds using Crossbow's low cost inertial device, and integration with GPS information and its feasibility are described by Cao *et al* (2002). Results show that the position accuracy of low cost SINS/GPS is just the same as that of GPS receiver when GPS data is available, and with a position error of 10 meters after 10 seconds with complete loss of GPS signals are observed.

Petovello *et al* (2001) dealt with little latency between INS and GPS information. The GPS measurements received from a GPS receiver are typically latent with respect to the IMU data, with the latency expected to be as large as half of a second. A Loosely coupled system was chosen here, this GPS/INS time offset is further compounded by the time required to process the GPS data before passing the position and velocity information to the INS filters. Two methods were dealt with this and in the first approach IMU data is buffered until appropriate GPS measurements are received. In their second approach, once the IMU data is received, it was processed and the navigation solutions buffered in memory. Then, when GPS update was

ready, it was applied to the appropriate INS solution, according to the GPS time tags. It was found that, the most current position was always the INS solution predicted from the last GPS update. Figure (5) gives a graphical representation of the updating process. Here the accuracy of the system depends on two things. First, the accuracy of the GPS solution will define the accuracy of the system. Second, the relative accuracy of the INS will determine the initial GPS error propagated forward in time. Mathematically, the real time position accuracy can be expressed as:

$$\sigma^2_{RT} = \sigma^2_{GPS} + \sigma^2_{INS}(I)$$

where:

σ^2_{RT} is the real time position error variance

σ^2_{GPS} is the GPS position error variance

$\sigma^2_{INS}(I)$ is the INS prediction error variance as a function of time

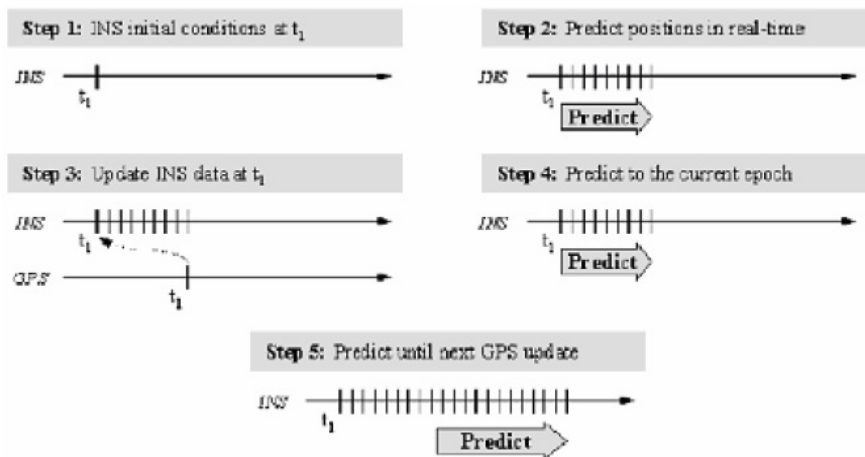


Fig. 5: Graphical Description Updating the INS with Latent GPS data [62].

Zhang (2003) developed a wave estimator to integrate DGPS with a medium accuracy IMU, for land positioning with the emphasis on accuracies at the metre level. A loosely coupled integration approach was developed, which uses carrier phase-smoothed Code Acquisition code-based DGPS positions and velocities as updates to the IMU. Two data sets were used to assess the GPS/INS integration results. First data set was from simulator and the second data set was from a field test for the field data set, the positioning accuracy had a Root Mean Square less than 0.5 m horizontally; the velocity had a Root Mean Square value less than 3.5 cm/s when using a Kalman filter. In case of using a wave estimator, the position accuracy had the same Root Mean Square value with that of using a Kalman filter; and the velocity accuracy had an Root Mean Square value no greater than 1.26 cm/s.

Sinpyo *et al* (2004) presented car test results on the estimation of alignment errors in the integration of a low-grade inertial measurement unit (IMU) with accurate GPS measurement systems. The car test was conducted with a low-cost solid-state IMU and carrier-phase differential GPS measurement systems. Test results showed that changes in the angular velocity improve the estimation of the lever arm between the GPS antenna and IMU. They also showed that changes in acceleration improve the estimation of the relative attitude between the GPS antenna array and IMU. The lever arm was estimated with a 10-cm error. The relative attitude was estimated with a half-degree error. An iterative scheme was used to improve the estimation of the alignment errors during postprocessing. The scheme was shown to be useful when the test car could not have sufficient changes in motion due to limitations in its path. With the given set of test data, the estimation error decreased as the number of iterations increased.

Jonghyuk K. and Salah S. (2004) presented the results of augmenting a GPS/INS navigation system with a Simultaneous Localisation and Mapping (SLAM). SLAM algorithm is a landmark based terrain aided navigation system that has the capability for online map building, and simultaneously utilising the generated map to bound the errors in the Inertial Navigation System (INS). In this paper, SLAM is augmented to GPS/INS system, which can provide information about the states of a vehicle without the need for a priori infrastructure such as GPS, ground beacons, or a preloaded map. Simulation results will be presented which shows that the system can provide reliable and accurate navigation/landmark-map solutions even in a GPS denied and/or unknown environments.

Babak A. and Krishnaprasa S. (2005) introduced for the first time particle filtering for an exponential family of densities. They prove that under certain conditions the approximated conditional density of the state converges to the true conditional density. In the realistic setting where the conditional density does not lie in an exponential family but stays close to it, it shows that under certain assumptions the error of the estimate given by an approximate nonlinear filter (which they call the projection particle filter), is bounded. They use projection particle filtering in state estimation for a combination of inertial navigation system (INS) and global positioning system (GPS), referred to as integrated INS/GPS. Finally illustrate via numerical experiments that projection particle filtering outperforms regular particle filtering in navigation performance, and extended Kalman filter as well when satellite loss-of-lock occurs.

Klaus *et al* (2006) perused an alternative processing strategy where the parameters of exterior orientation (EO) of an image sensor are determined by GPS/INS. Where EO parameters are transformed prior to the restitution, the scene would be systematically distorted. The reason is that the national coordinates are not Cartesian due to earth curvature and the unavoidable length distortion of map projections and in order to settle these corrections are approximations only. This strategy diminishes the horizontal distortions and eliminates the dominant part of the vertical distortions that are due to the earth curvature and the length distortion of the map projection. In addition, a dedicated strategy for the correction of the terrain-point coordinates was derived also for active imaging.

Jan *et al* (2006) developed an integrated navigation system based on MEMS inertial sensors and GPS for a VTOL-MAV. Special attention is paid to the handling of GPS outages. While usually periods without GPS aiding can be bridged using the unaided strapdown solution, the poor quality of the MEMS inertial sensors prohibits this approach here. Therefore, during GPS outages the accelerometer data is interpreted as approximate measurements of the local gravity vector. Additionally, the usage of a magnetometer providing measurements of the Earth's magnetic field is motivated and discussed. Finally, flight test results illustrate the performance of the resulting system, proving that the achieved attitude accuracy is sufficient for the automatic control of the MAV. This holds in situations with permanent GPS loss and dynamic maneuvering.

David *et al* (2006) presented a unique method for estimating key vehicle states body sideslip angle, tire sideslip angle, and vehicle attitude using Global Positioning System (GPS) measurements in conjunction with other sensors. A method is presented for integrating Inertial Navigation System sensors with GPS measurements to provide higher update rate estimates of the vehicle states. The influence of road side-slope and vehicle roll on estimating vehicle sideslip is investigated. A method using one GPS antenna that estimates accelerometer errors occurring from vehicle roll and sensor drift is first developed. A second method is then presented utilizing a two-antenna GPS system to provide direct measurements of vehicle roll and heading, resulting in improved sideslip estimation. Additionally, it is observed that the tire sideslip estimates can be used to estimate the tire cornering stiffnesses. The experimental results for the GPS-based sideslip angle measurement and cornering stiffness estimates compare favorably to theoretical predictions, suggesting that this technique has merit for future implementation in vehicle safety systems.

Wei *et al* (2007) analyzed the estimation performance of gyroscope drifts in INS/GPS integrated navigation systems, while system is in motion. Strapdown inertial navigation system (SINS) error model is augmented by inertial sensor bias, drift, and clock bias to improve the integration performance. Also, to estimate the augmented state error, instead of GPS position, GPS pseudorange and pseudorange rates are used. It is observed in this work that the vertical gyrodrift estimation is very weak in all cases of stationary, linear motion, and three-axis sway motion via Kalman filter covariance analysis. Zero update velocity (ZUPT) algorithm is proposed to improve the observability of vertical gyrodrift. Finally, the estimation results demonstrate that vertical gyrodrift can be better estimated for the sake of compensation afterward.

Sung *et al* (2007) used of GPS carrier phase (CP) and two-way satellite time and frequency transfer (TWSTFT) measurements, and present the time comparison results obtained with those two time-transfer methods, as well as those obtained from the GPS P3 data analysis. From the time comparison results, it was observed that the time comparison performance obtained by the GPS CP method is comparable to that obtained by TWSTFT, and the performance of both the GPS CP and the TWSTFT methods is much better than that of the P-code. And it appeared that the associated Allan deviations were slightly different depending on the type of atomic clock (hydrogen maser and cesium) used in the comparison.

Seong C. Y. and Kim B. D. (2008) proposed a robust IIR/FIR fusion filter and an INS/GPS integrated system designed with the fusion filter. In the fusion filter, an IIR-type filter (SPKF) and a FIR-type filter (MRHKF filter) are processed independently, and then the two filters are merged using the mixing probability calculated using the residuals and residual covariance information of the two filters. The merits of the SPKF and the MRHKF filter are integrated and the demerits of the filters are diminished through the filter fusion.

Consequently, the proposed fusion filter shows robustness against model uncertainty, temporary disturbing noise, large initial estimation error, etc. The stability of the fusion filter is verified by showing the closeness of two filters in the mixing/redistribution process and the upper bound of the error covariance matrices. This fusion filter is applied to an INS/GPS integrated system. The performance of the INS/GPS integrated system designed using the fusion filter is verified through a simulation under various error environments and is experimentally confirmed.

In past few decades, neural network and fuzzy control have been widely used in many applications such as control, navigation systems and so on. It is known that the neural network has learning ability and is a good choice for modeling dynamic and complex process. On the other hand the fuzzy control has an important feature where it is a very effective and practical approach to the modeling of the nonlinear, time varying and complex systems via the use a set of linguistic rules, which may come from a control engineer or an experienced operator for a particular system. So to obtain accurate navigation solution, many neural, fuzzy and combination between them were used in literatures.

Burak *et al* (2003) proposed a method to enhance the performance of a coupled global positioning/inertial navigation system (GPS/INS) for both air and land navigation applications during the GPS signal loss. Their method is based on using an artificial neural network (ANN) to intelligently aid the GPS/INS coupled navigation system in the absence of GPS signals. The proposed enhanced GPS/INS is used in the very dynamic environment of a tour of an autonomous van on the METU campus. Their GPS/INS+ANN system performance is thus demonstrated with the land trials. While Noureldin *et al* (2005) used ANN for multi-sensor system and worked on position only. Noureldin's work was done by using real data taken from Z-12 GPS receiver and a navigation-grade INS. With these navigation systems, reliable and accurate position information was obtained with accuracies of 0.5 m in all three directions for the specified data used above.

Adrian *et al* (2004) produced a new concept regarding GPS/INS integration, based on artificial intelligence, where adaptive neuro-fuzzy inference system (ANFIS) is presented. The GPS is used as reference during the time it is available. The data from GPS and inertial navigation system (INS) are used to build a structured knowledge base consisting of behavior of the INS in some special scenarios of vehicle motion. With the same data, the proposed fuzzy system is trained to obtain the corrected navigation data. In the absence of the GPS information, the system will perform its task only with the data from INS and with the fuzzy correction algorithm. This work shows, using Matlab simulations, that as long as the GPS unavailability time is no longer than the previous training time and for the scenarios a priori defined, the accuracy of trained ANFIS, in absence of data from a reference navigation system, is better than the accuracy of stand-alone INS. The flexibility of model is also analyzed. Also, Gizawy *et al* (2004) introduced a new GPS/INS integration technique using artificial intelligence systems. The proposed technique utilizes the Adaptive Neuro-Fuzzy Inference System (ANFIS), which combines the advantages of neuro computations and fuzzy reasoning. The ANFIS is utilized to model the relationship between the INS and GPS derived navigation information to accurately mimic the vehicle dynamics and provide accurate prediction of its position during GPS outages. While GPS measurements are available, the model is established and the internal structure of the ANFIS model is tuned to mimic the present vehicle dynamics. During periods of GPS signal blockage, the designed ANFIS architecture works in the prediction mode to estimate the position changes over time based on the INS velocity and azimuth. The results indicate that the proposed ANFIS model provides a significant improvement in the accuracy of the estimated position during GPS outages.

Rashad S. and Aboelmagd N. (2007) aimed to introduce a multi-sensor system integration approach for fusing data from INS and GPS utilizing artificial Neural Networks (ANN). A multi-layer perceptron ANN has been recently suggested to fuse data from INS and differential GPS (DGPS). Although being able to improve the positioning accuracy, the complexity associated with both the architecture of multi-layer perceptron networks and its online training algorithms limit the real-time capabilities of this technique. The INS and GPS data are first processed using wavelet multi-resolution analysis (WMRA) before being applied to the ANN. Results have demonstrated that substantial improvement in INS/GPS positioning accuracy could be obtained by applying the combined WMRA and ANN modules.

Neuro-fuzzy modules were used to fuse data from GPS and inertial sensors in real time by Aboelmagd (2006). This research optimized the operation of these modules by implementing a temporal window-based cross-validation approach during the update procedure. A field test data was used to examine the performance of the proposed method and the results discuss the merits and the limitations of the proposed technique. Also, the results showed that the proposed ANFIS module outperformed previous AI based data fusion modules with significantly low INS position errors during relatively long GPS outages. While Naser *et al* (2006) suggested an INS/GPS integration method based on artificial neural networks (ANN) to fuse uncompensated INS measurements and differential GPS (DGPS) measurements. The proposed method suggests two different

architectures: the position update architecture (PUA) and the position and velocity PUA (PVUA). Both architectures were developed utilizing multilayer feed-forward neural networks with a conjugate gradient training algorithm. Both PUA and PVUA mechanizations have shown a superior performance over the conventional INS/DGPS integration techniques, which are predominately based on the Kalman filter. The PVUA has shown the ability to provide the most stable and accurate INS/DGPS solution if compared to other techniques. Also, Aboelmagd *et al* (2007) optimized the AI-based INS/GPS integration schemes utilizing adaptive neuro-fuzzy inference system (ANFIS) by implementing, a temporal window-based cross-validation approach during the update procedure. The ANFIS-based system considers a non-overlap moving window instead of the commonly used sliding window approach. The proposed system is tested using differential GPS and navigational grade INS field test data obtained from a land vehicle experiment. The results showed that the proposed system is a reliable modelless system and platform independent module that requires no priori knowledge of the navigation equipment utilized. In addition, significant accuracy improvement was achieved during long GPS outages. Results showed that the proposed ANFIS module outperformed previous AI based data fusion modules with significantly low INS position errors during relatively long GPS outages. The accuracy of the system highly depends on the size of the temporal window utilized.

Hang *et al* (2006) introduced a novel SINS/GPS integration algorithm utilizing Hopfield neural network. This method obtains the optimal state estimation by minimizing the energy function of the Hopfield neural network. Furthermore this algorithm relaxes the assumptions made by the Kalman filter so it is more versatile. Finally the simulator results show that the new integration algorithm performs similarly to the Kalman filter. Also, it has some advantages such as fast convergence, unbiased and high precision during fusion process, despite of the inaccurate modeling errors, system disturbance, observation errors, and even the shortage of observation. In addition, it works in parallel computational mode and easily carried out in hardware of the Hopfield neural network.

Kai-Wei C. and Yun H. (2008) exploited the idea of incorporating artificial neural networks to develop an alternative INS/GPS integration scheme, the intelligent navigator, for next generation land vehicle navigation and positioning application. Real land vehicle test results demonstrated the capability of using stored navigation knowledge to provide real-time reliable positioning information for stand-alone INS-based navigation. For relatively short GPS outages, the KF was superior to the intelligent navigator. The results presented in this paper strongly indicate the potential of including the intelligent navigator as the core algorithm for INS/GPS integrated land vehicle navigation systems.

Conclusions:

Navigation and guidance of an autonomous vehicle require that the position and velocity of the vehicle must be determined. There are two main navigation systems used to determine the position and velocity for the moving vehicles, Global Positioning System (GPS) and Strapdown Inertial Navigation System (SDINS), where each of them has its strength and weakness. GPS requires a line of sight between the receiver and the satellite which can not be always met, lack of attitude, information, and jamming problems while INS, requires (initial position, velocity, and earth gravity) and its accuracy deteriorates with time.

In general, GPS/SDINS integration provides reliable navigation solutions by overcoming each of their shortcomings, including signal blockage for GPS and growth of position errors with time for SDINS. Most of the present navigation systems rely on Kalman filtering to fuse data from GPS and the SDINS. Present

Kalman filtering GPS/SDINS integration techniques have some inadequacies related to the stochastic error models of inertial sensors, immunity to noise, and observability. Thus integration of GPS and SDINS are expected to become more widespread as a result of low cost inertial sensors.

A fundamental difference between AI-based estimation methods and the other types of estimation methods such as Kalman is that AI-based methods do not use any mathematical models in the system dynamics and measurements. But on the other hand, AI-based estimation systems are that requiring more time during learning. Reviews of many researchers that are conducted to study, model, and integrate navigation systems for obtaining a reliable and accurate navigation solution is presented.

REFERENCES

- Aboelmagd, M., 2006. Enhancing the Update Procedure of Neuro-Fuzzy Modules used for Multi-sensor Navigation Systems, IEEE.
- Aboelmagd, N., E. Ahmed, R. Mahmoud, 2007. Optimizing neuro-fuzzy modules for data fusion of vehicular navigation systems using temporal cross-validation, *Engineering Applications of Artificial Intelligence*, 20: 49-61.
- Adrian, H., J. Rene and C. Fran, 2004. Fuzzy Corrections in a GPS/INS Hybrid Navigation System, *IEEE Transactions on Aerospace and Electronic Systems*, 40(2):

- Alexander, B., 2000. Improving the Accuracy and Resolution of SINS/DGPS Airborne Gravimetry, Ph.D.thesis. University of Calgary, Geomatic Engineering Dept.
- Amean, Z.S., 2001. Development of GPS Navigation Aiding for a Ballistic Missile, M.Sc. Thesis, Department of Control and Computers Engineering, University of Technology.
- Babak, A., S. Krishnaprasa, 2005. Approximate nonlinear filtering and its application in navigation, *Automatica*, 41: 945-956.
- Bian, H., Z. Jin and W. Tian, 2006. IAE-adaptive Kalman filter for INS/GPS integrated navigation system, *Journal of Systems Engineering and Electronics*, 17(3-9): 502- 508.
- Boulton, P., A. Read, G. MacGougan, R. Klukas, M.E. Cannon, G. Lachapelle, 2002. Proposed Models and Methodologies for Verification Testing of AGPS-Equipped Cellular Mobile Phones in the Laboratory. Proceedings of ION GPS 2002, Portland, OR, 24-27, pp: 200-212.
- Burak, H., M. Aydan and E. Ismet, 2003. GPS/INS Enhancement Using Neural Networks for Autonomous Ground Vehicle Applications, Proceedings of the 2003 IEEE/IRISJ International Conference on Intelligent Robots and Systems Las Vegas, Nevada.
- Caciotta, M., F. Leccese and E. PiuZZi, 2007. Study of a New GPS-Carriers Based Time Reference with High Instantaneous Accuracy, The Eighth International Conference on Electronic Measurement and Instruments, ICEMI.
- Cannon, M.E., 1999. Development and Testing of an Integrated INS/GPS Cross-Linked System for Sub-Meter Positioning of a CF-188 Jet Fighter, Institute of Navigation Annual Meeting / Cambridge / June 28-30.
- Cao, F.X., D.K. Yang, A.G. Xu, J. Ma, W.D. Xiao, C.L. Law, K.V. Ling and H.C. Chua, 2002. Low cost SINS/GPS integration for land vehicle navigation, *Intelligent Transportation Systems*, IEEE, pp: 910 - 913.
- Caron, F., D. Emmanuel, D. Pomorski, P. Vanheeghe, 2006. GPS/IMU data fusion using multisensor Kalman Filtering: introduction of contextual aspects, *Information Fusion*, 7: 221-230.
- Chin, W., Tan and P. Sungsu, 2005. Design of Accelerometer-Based Inertial Navigation Systems, *IEEE Transactions on Instrumentation and Measurement*, 54(6).
- Chih, H., J. Hung and H. Wei, 2007. A Genetic Approach for Coordinate Transformation Test of GPS Positioning, *IEEE Geoscience and remote sensing letters*, 4(2):
- Dan, L., R. Wu, Z. Su and W. Huang, 2007. A Two Stage GPS Anti-jamming processor for Interference Suppression and Multipath mitigation, *IEEE*.
- Daniel, N., A. Mazin and M. Dennis, 2007. A Methodology for the Evaluation of a GPS Receiver Performance in Telematics Applications, *IEEE Transactions on Instrumentation and Measurement*, 56(1):
- David, J., 1996. Analysis of an Upgraded GPS Internal Kalman Filter, *IEEE AES Systems Magazine*.
- David, M. and P. Bradford, 2007. Cascaded Kalman Filters for Accurate Estimation of Multiple Biases, Dead-Reckoning Navigation, and Full State Feedback Control of Ground Vehicles, *IEEE Transactions on Control Systems Technology*, 15(2):
- David, M., R. Jihan and G. Christian, 2006. Integrating INS Sensors With GPS Measurements for Continuous Estimation of Vehicle Sideslip, Roll, and Tire Cornering Stiffness, *IEEE Transactions on Intelligent Transportation Systems*, 7(4):
- Ding, W. and J. Wang, 2007. Vehicle Dynamics Based De-Noising for GPS/INS Integration, *IGNSS*, the University of New South Wales, Sydney, Australia, 4-6.
- Dorota, A.G. and J. Wang, 1998. Gravity Modeling for High-Accuracy GPS/INS Integration, *Navigation*, 45(3): 209-220.
- Eduardo, M. and D. Hugh, 1999. A high integrity navigation architecture for outdoor autonomous vehicles, *Robotics and Autonomous Systems*, 26(8): 1-97.
- Farhan, A., J. Kenneth, 2000. Extended Kalman filter synthesis for integrated global positioning/inertial navigation systems, *Applied Mathematics and Computation*, 115: 213-227.
- Faulkner, M., S.J. Cooper and P.A. Jeary, 2002. Integrated MEMS/GPS navigation systems, *Position Location and Navigation Symposium*, IEEE, pp: 306-3.
- Gillent, J., B.M. Scherzinger and E. Lithopoulos, 2001. Inertial/GPS System for Seismic Survey, *International Symposium on Location Based Services for Cellular Users*, Locellus.
- Gizawy, M., N. El-Sheimy, R. Taha and A. Noureldin, 2004. Neuro-Fuzzy System for GPS/INS Integration, *The European Navigation Conference*, GNSS.
- Hang, S., Z. Jihong and S. Zengqi, 2006. A Novel SINS/GPS Integration Algorithm Based on Neural Networks, proceedings of the 6th world Congress on Intelligent Control and Automation, June 21-23, Dalian, China.

- Hyung, C., G. Jang and L. Gyu, 2003. Mobile Station Location Using Hybrid GPS and a Wireless Network, *IEEE transaction on Aerospace and Electronic Systems*.
- Ismaeel, S.A., 2003. Design of Kalman Filter of Augmenting GPS to INS Systems, Ph.D. Thesis, Computer Engineering Dept., College of Engineering, Al-Nahrain University.
- Jahn, A., 2001. Propagation Considerations and Fading Countermeasures for Mobile Multimedia Services. *International Journal of Satellite Communications*, 19: 223-250.
- Jan, W. and F. Gert, 2004. Tightly coupled GPS/INS integration for missile applications, *Aerospace Science and Technology*, 8: 627-634.
- Jan, W., M. Oliver, S. Christian and F. Gert, 2006. An integrated GPS/MEMS-IMU navigation system for an autonomous helicopter, *Aerospace Science and Technology*, 10: 527-533.
- John, B.H., A.M. Lee and J.C. Pierre, 2007. Prediction of global positioning system total electron content using Neural Networks over South Africa. *Journal of Atmospheric and solar-terrestrial physics*, 69: 1842-1850.
- Johnson, R., J. Sasiadek and J. Zalewski, 2000. Kalman Filter Enhancement for UAV Navigation, InterNet Site.
- John, W., S. Peter and F. John, 2005. Multipath-Adaptive GPS/INS Receiver, *IEEE Transactions on Aerospace and Electronic Systems*, 41(2):
- Johan, B. and W. Steyn, 2008. Kalman filter configurations for a low-cost loosely integrated inertial navigation system on an airship, *Control Engineering Practice*, doi: 10.1016/j.conengprac.2008.04.01 1.
- Jonghyuk, K., S. Salah, 2004. SLAM aided GPS/INS Navigation in GPS Denied and Unknown Environments, Presented at GNSS 2004 ,The 2004 International Symposium on GNSS/GPS, Sydney, Australia, 6-8.
- Kai-Wei, C., H. Yun, 2008. An intelligent navigator for seamless INS/GPS integrated land vehicle navigation applications, *Applied Soft Computing*, 8: 722-733.
- Kevin, J., C. Michael, S. Nechyba and A. Antonio, 2003. Embedded Low Cost Inertial Navigation System, Florida Conference on Recent Advances in Robotics, FAU, Dania Beach, FL, May 8-9.
- Klaus, L., 2006. Approximate direct georeferencing in national coordinates, *ISPRS Journal of Photogrammetry and Remote Sensing*, 60: 239-255.
- Klukas, R., G. Lachapelle, C. Ma and G. Jee, 2003. GPS Signal Fading Model For Urban Centers. *IEE Proceedings – Microwaves, Antennas and Propagation*, 150(4): 245-252.
- Knight, D.T., 1999. Rapid Development of Tightly-coupled GPS/INS Systems, *Proceedings of ION International Technical Meeting*, Nashville, Tennessee.
- Kralj, D., T. Hsu, L. Carin, 2000. On GPS Positioning and Integrity Monitoring, *IEEE Transactions on Aerospace and Electronic Systems*, 36(1):
- Ladetto, Q., V. Gabaglio and B. Merminod, 2001. Two Different Approaches for Augmented GPS Pedestrian Navigation, *International Symposium on Location Based Services for Cellular Users*, Locellus.
- Lachapelle, G., M.E. Cannon, R. Klukas, S. Singh, R. Watson, P. Boulton, A. Read and K. Jones, 2004. Hardware Simulator Models and Methodologies for Indoor Performance Assessment of High Sensitivity Receivers. *Canadian Aeronautics and Space Journal*, 50(3): 151-168.
- Lee, Y.C. and D.G. O’Laughlin, 1999. A Performance Analysis of a Tightly Coupled GPS/ Inertial System for two integrity Monitoring Methods, *The MITRE Corporation*.
- Lichun, L., T. Zengshan, H. Shun, 2001. An algorithm for integrating GPS/INS attitude determination system, *Proceedings IEEE International Conference on Radar*, CIE, pp: 167-170.
- Li, Y., X. Xi, 2007. Combining FFT and Circular Convolution Method for High Dynamic GPS Signal Acquisition, the Eighth International Conference on Electronic Measurement and Instruments, ICEMI.
- Loebis, D., R. Sutton, J. Chudley and W. Naeem, 2004. Adaptive tuning of a kalman filter via fuzzy logic for an intelligent AUV navigation system, *Control Engineering Practice*, 12: 1531-1539.
- Ma, C., G. Jee, G. MacGougan, G. Lachapelle, S. Bloebaum, 2001. Cox, G., Garin, L., and Shewfelt, J., GPS Signal Degradation Modeling, *ION GPS 2001, Session C2*, Salt Lake City, UT, September 11-14, pp: 882-893.
- Mao, G., S. Drake and B. Anderson, 2007. Design of an Extended Kalman Filter for UAV Localization, *IEEE Information, Decision and Control*.
- Mayhew, D.M., 1999. Multi-rate Sensor Fusion for GPS Navigation using Kalman Filtering, M.Sc. thesis. Virginia Polytechnic Institute and state University, Electrical Engineering Dept.
- Michael, K. and A. Diane, 1998. New Low Cost Avionics with INS/GPS for a Variety of Vehicles, *IEEE AES Systems Magazine, Robotics and Autonomous Systems* 26 (1999) 81-97.
- Mohammed, M., S. Klaus, 2001. Digital image georeferencing from a multiple camera system by GPS/INS, *ISPRS Journal of Photogrammetry and Remote Sensing*, 56: 1-12.
- Mohammad, S., M. Dennis and N. Daniel, 2007. GPS C/No Estimation in the Presence of Interference and Limited Quantization Levels, *IEEE Transactions on Aerospace and Electronic Systems*, 43(1):

- Mladen, M., S. Zoran and B. Stevan, 2006. A Comparison of Accuracy using a GPS and Low-cost DGPS, *IEEE Transactions on Instrumentation and Measurement*, 55(5):
- Naser, E., K. Chiang and A. Noureldin, 2006. The Utilization of Artificial Neural Networks for Multisensor System Integration in Navigation and Positioning Instruments, *IEEE Transactions on Instrumentation and Measurement*, 55(5):
- Nassar, S., 2003. Improving the Inertial Navigation System (INS) Error Model for INS and INS/DGPS Application, Ph.D Thesis. University of Calgary, Geomatic Engineering Dept.
- Noureldin, A., A. Osman and N. El-Sheimy, 2005. A Neuro-Wavelet Method for Multi-Sensor System Integration for Vehicular Navigation, *Meas. Sci. Technol.*, 15: 404-412.
- Ohlmeyer, E.J., T.R. Pepitone and B.L. Miller, 2001. Assessment of Integrated GPS/INS for the EX- 171 Extended Range Guided Monition, InterNet Site.
- Ou, X., W. Zhou and J. Yu, 2005. Study on GPS Common-view Observation Data with Multiscale Kalman Filter based on correlation Structure of the Discrete Wavelet Coefficients, *IEEE Transaction*.
- Park, M., 2004. Error Analysis and stochastic Modeling of MEMS based Inertial sensors for Land Vehicle Navigation Application, M.Sc Thesis. University of Calgary, Geomatic Engineering Dept.
- Pérez-Fontán, F., B. Sanmartin, A. Steingass, A. Lehner, J. Selva, E. Kubista and B. Arbesser-Rastburg, 2004. Measurements and Modeling of the Satellite-to- Indoor Channel for Galileo. *Proceedings of ION NTM 2004*, San Diego, Ca, 26-28, pp: 190-202.
- Peterson, B., D. Bruckner and S. Heye, 1997. Measuring GPS Signals Indoors. *Proceedings of the ION GPS1997*, Kansas City, Missouri, September 16-19, 1997, pp: 615-624.
- Petovello, M., M.E. Cannon and G. Lachapelle, 2001. Development and Testing of a Real-Time GPS/INS Reference System for Autonomous Automobile Navigation, *Proceedings of ION GPS-0 1*, Salt Lake City, UT, September 11-14.
- Rashad, S. and N. Aboelmagd, 2007. Sensor Integration for Satellite-based Vehicular Navigation Using Neural Networks, *IEEE Transactions on Neural Networks*, 18(2):
- Salytcheva, A.O., 2004. Medium Accuracy INS/GPS Integration in Various GPS Environment, M.Sc Thesis. University of Calgary, Geomatic Engineering Dept.
- Sato, G., T. Asai, T. Sakamoto and T. Hase, 2000. Improvement of the positioning of a software-based GPS receiver using a 32-bit embedded microprocessor, *IEEE Transactions on Consumer Electronics*, 46(3):
- Seong, C.Y. and B.D. Kim, 2008. Adaptive IIR/FIR fusion filter and its application to the INS/GPS integrated system. *Automatica*, doi: 10.1016/j .automatica.2007. 11.009.
- Shin, E.H., 2001. Accuracy Improvement of Low Cost INS/GPS for land Application, M.Sc Thesis. University of Calgary, Geomatic Engineering Dept.
- Sinpyo, H., H.L. Man, K. Sun and C. Ho, 2004. A Car Test for the Estimation of GPS/INS Alignment Errors, *IEEE Transactions on Intelligent Transportation Systems*, 5(3):
- Sndlinger, R., 1978. Investigations on the Optimization of Aided Inertial Navigation System, AGARD No.95, Strapdown Systems, pp: 124-139.
- Steingass, A. and A. Lehner, 2003. Land Mobile Satellite Navigation – Characteristics of the Multipath Channel. *Proceedings of ION GPS/GNSS 2003*, Portland, OR, pp:1016-1022.
- Sung, W., H. Dong-Hwan, K. Tae and J. Sang, 2002. Design and Implementation of an Efficient Loosely-Coupled GPS/INS Integration Scheme, Chungnam National University, KOREA.
- Sung, Y., Y. Hoon, K. Young, J. Youn, W. Seong and B. Chang, 2007. Comparison of Time Transfer Using GPS Carrier Phase and Multichannel Two-Way Data in East Asia, *IEEE Transactions on Instrumentation and Measurement*, 56(2):
- Wang, B., J. Wang, J. Wu and B. Cai, 2003. Study on Adaptive GPS/INS Integrated Navigation System, *IEEE*.
- Watson, J.R.A., 2005. High-Sensitivity GPS L1 Signal Analysis for Indoor Channel Modelling. MS.c.,Thesis, published as Report No. 20215, Department of Geomatics Engineering, The University of Calgary.
- Wei, G., N. Qi, Z. Guofu and J. Hui, 2007. Gyroscope Drift Estimation in Tightly-coupled INS/GPS Navigation System, *Second IEEE Conference on industrial Electronics and Applications*.
- Wei, W., Y. Zong, R. Rong, 2006. Quadratic extended Kalman filter approach for GPS/INS integration, *Aerospace Science and Technology*, 10: 709-7.
- Xuchu, M., W. Massaki, H. Hideki, 2000. Nonlinear GPS Models for Position Estimate Using Low-cost GPS Receiver.
- Zhang, X., 2003. Integration of GPS with A Medium Accuracy IMU for Metre-level positioning, M.Sc Thesis. University of Calgary, Geomatic Engineering Dept.