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Survey of Inertial Navigation Sensor with Aiding Systems

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Abstract: In the recent trends, it is noticeable that INS/GPS system is used widely. In contrast to stand-alone system, integrated systems are much reliable. The main motive of integrating the INS/GPS system is to overcome their individual discrepancies. The existing technologies comprise stand-alone GPS, INS, MEMS/GPS, RISS/GPS using Mixture Particle filtering, CP-DGPS/INS using wheel encoder and electronic compass, INS/ANN, fuzzy logic. This paper offers to date survey of most of the major content to the pool of INS/GPS outcomes for land vehicles. Also, the operation and comparison of their various attributes is summarized. The readers are provided with a better insight of all the existing technologies, overcoming the short-comes of one over the other, thereby identifying the areas for future research.

I. INTRODUCTION

Inertial Navigation System (INS) is a dead-reckoning, self sustained navigation system, which determines the attitude, velocity, and position of a moving body from the knowledge of the previous states and the measurement of the motion. It is a navigation aid that uses a gravity computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to calculate position and orientation respectively. Global Positioning System (GPS) is a satellite navigation system that provides location information anywhere on or near the Earth where there is a unobstructed line of sight. It provides accurate long-term position and velocity information at a relatively low frequency data rate. Generally, stand-alone systems have some discrepancies that makes them unreliable for wide use. In the case of inertial navigation sensors, errors and sensor drifts accumulates with time. While GPS has its own limitations such as low sampling rate, signal interference, multipath signal propagation, henceforth cannot achieve continuous localization in urban canyons, tunnels, and other environments where satellite signals are blocked.

Inorder to improve the navigation performance, integration of systems is used. In INS/GPS integrated system, GPS information can be used to correct the INS errors and improve the long-term accuracy of INS, while on the other hand, INS provides position information during GPS outages, can assist GPS signal reacquisition after an outage thereby reducing the search domain required for detecting and correcting the GPS cycle slips. In the integration system, Kalman filter has been widely adopted as the standard optimal estimation tool. This filter is employed to fuse GPS and INS measurements, which requires a priori knowledge about the stochastic and deterministic parameters of both the systems. Compared to other techniques, Kalman filter is more preferred because, it gives better estimate and less complexity.

II. RELATED WORK

A literature survey yields overview and survey of INS/GPS integration issues and solutions. It is observed from the paper published in 2008 by Priyanka Aggarwal [1], that has explained about the acceptable navigation accuracies for civilian vehicles. It deals with the misalignment of the body frame with the inertial sensor frame while taking into account the non holonomic constraints. Here, the inertial navigation sensor is classified according to the number of sensors used in the system. The comparison is done between the first inertial system consisting of three accelerometers and three gyroscopes (Full IMU) ,and the second inertial system that has one gyroscope and two horizontal accelerometers (Partial IMU). It is inferred from the paper that partial IMU with non holonomic constraint gives a result with 15 degrees misalignment usually cause 20% less degradation than full IMU.

Further, the navigation system can also be formed by the intergration of DGPS, three accelerometers, gyroscope along with barometer[2]. The barometer is used to measure the altitude pressure, which in turn estimates the change of road grade, which is needed to remove the gravity component sensed by the accelerometers. The accurate measurement requires the information about the pressure and temperature at the mean sea level. The system is most suited for the hillside navigation with reduced sensor outputs during GPS outages of less than 1 minute. Generally, the integration of DR/GPS is preferred in most of the low cost urban portable navigation sytems[3]. In this system, when GPS signals are available, only its output is taken into account. But, during GPS outages, dead reckoning with three accelerometers and one gyroscope are used to estimate the navigation data. Eventhough the position and velocity measurements obtained through this sytem is not appreciable, it provides acceptable results in urban navigation.

While in another paper published in 2010 by J-H Wang [4] explains about a self-contained dynamic-aided error correction method, that overcomes rapid navigation error drift generated in the absence of aiding sensors. It is observed that the dynamics dependent variables are measured during the stationary and straight line motion of the vehicle. The vehicle dynamic identification system used in this paper is fuzzy logic. It is reasoned out that this method is highly suitable for land vehicle navigation in urban canyon, where severe GPS signal degradation, frequent vehicle halt and turning dynamics exist. The paper published by Xu Li[5] in the year 2010 presents a novel adaptive fault-tolerant multisensor navigation strategy for unmanned vehicles on the automated highway system. It explains about the generation of the reference trajectory path by means of the INS, updation of the position and orientation by means of CP-DGPS, Wheel Encoder and Electronic Compass. It is observed that in this method the fuzzy logic has also been implemented to obtain a highly reliable navigation system that can assure a safe running of the automated vehicles in complex situations. Even in cases of sensor failures, the system performance does not deteriorate.

Similarly in one another paper published by Jacques Georgy [6] in 2010, RISS with MEMS based inertial sensors are used for targeting a low cost navigation solution for land vehicles. This paper depicts the usage of one single axis gyroscope, two axis accelerometer (RISS) and vehicle's odometer integrated with GPS, to obtain a 3D navigation solution. Contradicting to the traditional technique of using Kalman filtering for integration, here, enhanced version of particle filtering, that is Mixture particle filtering (Mixture PF) is used. Additionally, the performance of proposed 3D navigation solution using Mixture PF for RISS/GPS is compared with the proposed system using Kalman and Particle filtering for 2D and 3D solutions. It is extrapolated that the proposed 3D navigation solution with Mixture PF for RISS/GPS outperforms all other navigation solutions and demonstrates good performance for MEMS-based sensors during GPS outages at prolonged duration. Moreover, the paper published in 2009 by Jean Laneurit[7] presents an algorithm for lane-level road vehicle navigation that integrates GNSS, dead-reckoning (odometery and gyro), and mapped data in the fusion process. Additionally, the proposed method brings forth the map-matching (EMAP) at lane-level because, on one hand it allows the tracking of multiple hypothesis and on the other hand, it provides probability values of lane occupancy for each candidate segment. The data fusion filter employed here is Particle Filtering. It is dissoluted from this paper that better results can be obtained in usual situations of poor satellite coverage.

The paper published by Aydan M. Erkmen[8] explains about using an Artificial Neural Network(ANN) to aid the GPS/INS coupled navigation system during GPS outages. In this paper, a cost effective solution has been proposed, that uses ANN, to estimate the position from learned GPS/INS behavioural patterns. It is found out that ANN system is trained with the position differences computed every second during the GPS on phase. And when the GPS signal is lost, the trained ANN generates the position difference estimates. It is deduced that the GPS/INS position value exactly matches with the INS/ANN in the east and vertical direction.

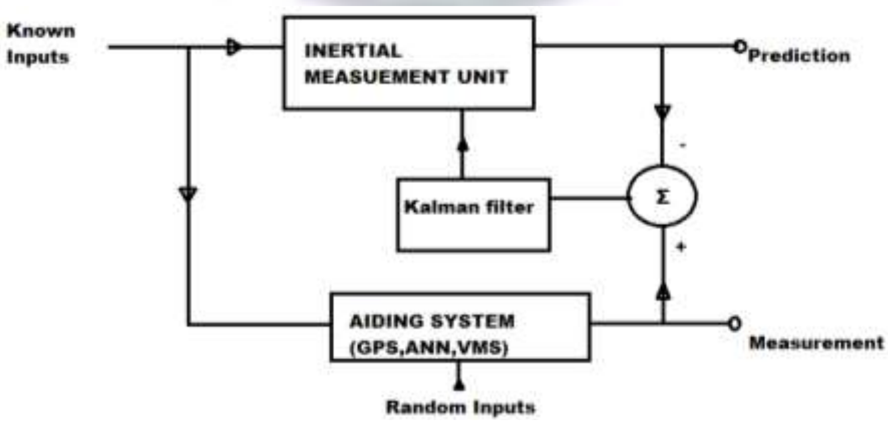

Figure 1.1: Block diagram of INS integration with aiding system Using Kalman filter

Kalman filter is basically used in all inertial navigation systems. It is a set of mathematical equations that provides an efficient computational (recursive) means to estimate the state of process, in a way that minimizes the mean of the squared error. Generally, for linear systems standard Kalman filter is used, but most of the navigation systems are non-linear. Henceforth, Extended Kalman filter (EKF) is preferred.

- Kalman filter is a powerful tool when it comes to controlling noisy systems. But many real world problems are non-linear, which requires amendments to linear solutions. So if the non-linear models can be expressed in a state-space setting, then the Kalman filter will find utility by applying linearization at each time step.

- The EKF extends the scope of Kalman filter to nonlinear optimal filtering problems by forming a Gaussian approximation to the joint distribution of state and measurements using a Taylor series based transformation.

- Because of the EKF's recursive nature, it runs in real time system, using only the present input measurements and the previously calculated states with its uncertainity matrix, not requiring any additional past information.

In general, inertial naviagtion systems are non-linear, hence EKF is implemented in these systems. The most common LVN multisensor configuration incorpates and integrated INS/GPS system based on Kalman filter.

The paper published in the year 2008 by Jian Rong[9] explains about the comparison of First Order Extended Kalman Filter (FEKF), Second Order Extended Kalman Filter (SEKF) and Rauch Tung Striebel-Smoother for GPS/DR integrated navigation system. In this paper, three algorithms mentioned are simulated and the algorithm performance is compared by the simulation results. The general conclusion drawn in the paper shows that SEKF and FEKF employed for same parameter and conditions, proves SEKF as the better estimator for the states of land vehicle integrated GPS/DR systems. This paper also implements Extended Forward-Backward smoother with the Second Order EKF estimates. On comparison, It is concluded that SEKF-RTS shows better results, and superior performance than FEKF and SEKF in nonlinear systems.

Another paper published in the year 2010 by Sameh Nassar[10] explains about Two Filter smoother (TFS) algorithm applied in LVN system. RTSS algorithm used in the previous paper is compared with that of FKF, while here TFS algorithm for MEMS-IMU is employed. Generally, TFS and RTSS overcomes the frequent GPS signal loss and rapid time growing inertial navigation errors in INS/GPS system. Hence, it is concluded from the test results that position error in TFS and RTSS is almost same for east, north and vertical direction, while for FKF, it is comparatively high. And the same test conducted for MEMS/GPS symbolizes that position error for TFS/RTSS is slightly varying but in FKF, it is hundred folds high. From the above discussion, it is interpreted that Extended kalman filter is widely used for non-linear systems. While for INS/GPS systems RTSS, TFS algorithm is used for better estimates of position, velocity and attitude measurements. Particle Filtering is one another non-linear technique to accommodate arbitrary inertial sensor characteristics, motion dynamics and noise distributions. An enhanced version of Particle Filtering, namely Mixture Particle Filtering has also been implemented.

A. Kalman Filters and Smoothers

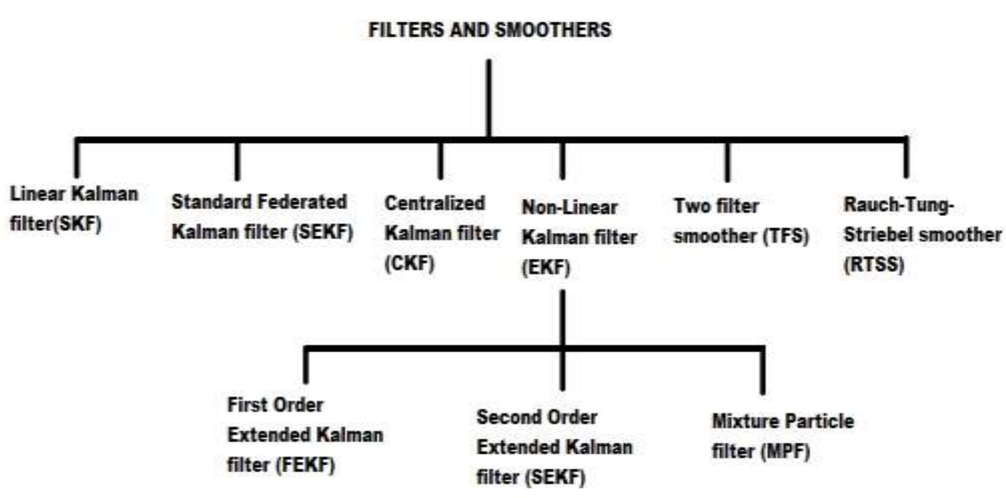

Figure 1.2: Types of Kalman filters and Smoothers used

In the comparison of the performance[9] of FEKF, SEKF and SEKF-RTS for GPS/DR system., It is analyzed that maximum error in position estimation in East and North direction is minimum for SEKF-RTS around 2.1m and 5m respectively, while for FEKF and SEKF, it is large. The error in velocity estimation along East and North direction is 0.04 m/s and 6 m/s for SEKF-RTS, on the other hand, it is very high for FEKF and SEKF. The two filter smoother technique[10] is used to reduce the overall error generated in INS/GPS. The mean position error for ADI MEMS/GPS SPP with no simulated outage is almost equal for TFS and RTSS compared to FKF, which is high. On the other hand, the mean position error of Tactical–grade IMU (LN200)/DGPS with simulated outages is highest for FKF and least for TFS. It is concluded that 3-D position errors for IMU (LN200)/DGPS is very high for FKF (3.162m), while for TFS and RTSS it is almost same and very small (around 0.146m). The improvement in rectifying the error is very good for RTSS and TFS (95.4%). In ADI MEMS/GPS SPP simulated outages, the mean position error for TFS and RTSS is equal, while for FKF it is 60 folds higher than both. The 3-D position errors for ADI MEMS/GPS SPP is 25 times higher for FKF system than TFS and RTSS system. The improvement of its accuracy is high for TFS and RTSS. So, it is concluded that TFS and RTSS smoothing algorithms is much better for reduction of INS/GPS error, compared to FKF.

In one another paper [6], RISS with vehicle's odometer and GPS is used. The paper compares the performance of 3-D navigation solution using Mixture particle filter for RISS/GPS and compares it with four navigation solutions such as 3-D KF for INS/GPS, 2-D KF for RISS/GPS, 2-D Mixture PF RISS/GPS, 3-D SIR for RISS/GPS. It is inferred that maximum altitude average error and 2D horizontal position error during GPS outages (Montreal trajectory) is minimum in 3-D MPF for RISS/GPS. While, it is 12 fold high for KF OBD 3-D IMU/GPS. For Toronto trajectory maximum 2-D horizontal position error and altitude average error during GPS outages is almost equal for 3-D MPF and 2-D MPF in RISS/GPS (3 m, 12 m respectively). In Kingston Trajectory, maximum altitude average error during GPS outages is low for 3-D (SIR) PF and for RISS/GPS (7.17 m), while, it is high for KF OD 3-D IMU/GPS. The 2-D maximum position error is low for 3-D MPF, 2-D MPF RISS/GPS and high for other methods.

B. Comparison of aiding methods for INS/GPS

Till now, a survey about the various implementations of INS with the aiding sensors was done. Therefore, in order to have a vivid vision about INS in various applications, the attributes are going to be compared in a table format.

S. No	INS and its aiding systems	Accuracy	Robustness	Cost Effective	Type of filter(s) used	Implementation complexity	Reliability	Error	Applications
1	Stand-alone INS(full and partial IMU)	Less accurate	Upto 15 degree misalignment	Highly economical	EKF	Less	Less	High in Full IMU	Limited.
2	Dynamics aided INS	Less accurate but provides stable results	Moderate	Economical	EKF	Less	Less	For 3min GPS outage,position-27m & velocity-0.66m/s	Low cost
3	SINS/CP-DGPS/Wheel Encoder/Electronic Compass	Highly accurate	High	High cost	CKF and FKF	High	High	Negligible	Limited.
4	RISS with MEMS/GPS and Mixture PF 3D	Outperforms all proposed methods	Higher in 3-D than 2-D	High cost	Mixture PF	More than 2-D & 3-D KF,2-D Mixture PF,3-D SIR PF	Comparitively high	Much lesser than others	Small -Region
5	GNSS/DR/EMAP	Lane level accuracy	Medium	High cost	PF	Increases in crossroads	very high	Position-0.345m (mean)	lane level navigation
6	GPS/INS + ANN	Highly accurate	High	Moderate	EKF	Node dependent	High	Less	Sophisticated

Figure 1.3: Comparison table for aiding methods in INS/GPS.

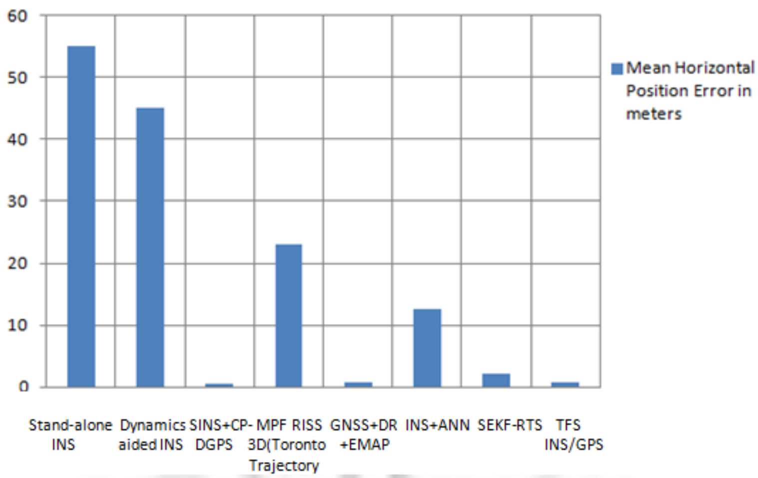

Figure 1.4: Mean horizontal position error for 5minutes GPS outage

Fig 1.1 depicts the various aspects of different integration systems of INS in a tabular form. It is concluded that, depending upon the requirements, different aiding systems can be employed to have a better navigation outputs. Fig 1.2 shows a graph that highlights the mean position error in the horizontal direction during 5 minutes GPS outage. It is discovered that SINS/CP-DGPS, GNSS/DR/EMAP, TFS systems shows very less position errors i.e., 0.145m, 0.1568m and 0.57 m respectively.

III. FUTURE WORK

In the previous sections, several implementations of INS/GPS with several aiding systems was discussed. Eventhough they have sufficient accuracy, they have their own demerits. An inertial navigation system consisting of INS/VMS is propsed to reduce the accumulation errors during GPS outages. VMS (Vehicle Motion Sensor) is a sensor that measures the distance travelled by the vehicle by means of the wheel rotations, which makes it highly reliable. Hence, these two sensors are integrated to have a better estimate of the navigation results. During the GPS outages, the stand-alone INS errors gets piled up with time. Kalman filter used in Stand-alone INS give erroneous estimates due to the lack of measurement update. Here, VMS comes into action where the postion estimates from the integrated system provides the better results.

The non-linear Kalman Filter used in INS/VMS system will give better results than the stand-alone INS. Furthermore to improve the performance of the integrated system, higher order non-linear Kalman Filters and Smoothers can be used.

IV. SUMMARY

This paper has presented the survey of several integrated systems with its pros and cons. It is summarized that stand-alone systems are unreliable. Henceforth, INS is integrated with various other systems assisted by Kalman Filter and Smoothers. A comparison is done based on different system's performance and formulated a graph based on their position errors. Finally, topics for future research are identified.

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