Integration of Low-Cost IMU with MEMS and NavIC/IRNSS Receiver for Land Vehicle Navigation

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Integration of Low-Cost IMU with MEMS and NavIC/IRNSS Receiver for Land Vehicle Navigation

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BIOGRAPHY

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Laxminarayana Parayitam is the Professor and Director of NERTU, OU. At present, his areas of research interests are Signal Processing, Communication and Navigation for Development of Real Time GNSS software Receivers, Integration of GNSS with other Navigation systems for Autonomous Navigation, Speech technologies for Speech-to-Speech interface for Man-Machine communication, Instruments for Biotech Industries. He is passionate about industry-institute interaction and start-ups.

ABSTRACT

Global Navigation Satellite System (GNSS) based navigation is ubiquitous for land vehicles to any known or unknown location. Location coordinates of the land vehicles are obtained with GNSS and maps for choosing the route and guidance for driving. Similarly, in near future driver-less cars are expected to enter into the market. For this purpose only GNSS is not sufficient for navigation, the best complementary system for GNSS is Inertial Navigation System (INS). In this paper, we proposed the loosely coupled integration of low cost Micro Electro Mechanical Systems (MEMS) based Inertial Measurement Unit (IMU) with NavIC (Navigation with Indian Constellation). As the NavIC is a regional navigational satellite system, it can be used only in India and surroundings. Low-cost MEMS based IMU BMI160 and a NavIC enabled receiver is used to evaluate the performance of the loosely coupled integrated navigation solution. The calibration of the IMU is done using Allan variance with stationary data. Generally, low cost IMU is calibrated or updated using GNSS measurements. However, in the absence of GNSS and the vehicle is stationary, IMU is calibrated and updated using Zero Velocity Update (ZVU) method.

In this paper, the performance of loosely coupled integration of IMU with GNSS is analysed in three different modes with NavIC, GPS and NavIC+GPS in the urban scenario, mainly in terms of outage period and the statistical accuracy measures within the outages. The experimental results shows that integration of low-cost IMU with NavIC+GPS outperforms the integration with NavIC and GPS separately.
Keywords: GNSS, MEMS IMU, NavIC and ZVU

1. INTRODUCTION

An autonomous vehicle should be harmless to anything for either people or properties like vehicles and buildings. For that purpose the navigation system play crucial role in the autonomous vehicle because it is necessary to provide reliable, accurate and continues solution in any weather/environmental conditions. Like civil aviation requirements, continuity, availability, accuracy and integrity of navigation measurements are very much essential for autonomous vehicles without drivers. GNSS will provide the position, velocity and time of the vehicle with the required accuracy. But there is a possibility of non-availability of GNSS signals or degradation, due to spoofing, jamming, obstruction of signals by buildings, trees etc., will make the GNSS alone, not capable to provide possible required navigation solution for autonomous systems. Many other sensors like IMU, Odometer, Camera, LIDAR and RADAR are available to overcome the issues of GNSS. However, the accuracy of the navigation solution degrades with time and require reference position for obtaining the position of the vehicle using these sensors. Sensor fusion will help to overcome the shortcomings of individual sensors and provide reliable navigation for autonomous systems [1]. Among all these sensors, GNSS and IMU are useful for finding the coordinates of the vehicle globally or with respect to local coordinate system, such that the navigation path for reaching the destination. Therefore, the best complementary system for GNSS is Inertial Navigation System (INS). The

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integrated GNSS/INS system will provide continuous and reliable navigation solution include position, velocity and attitude in any circumstances compared with the individual systems.

In the early days of GNSS/INS research, the researchers used navigation grade or tactical grade IMUs, this type of system should provide very good navigation solution in any weather conditions. The above IMU sensors are very high cost, it may possibly leads to burden for end customers of autonomous vehicles, therefore the utilization of low cost devices are essential for mass-market land vehicle navigation [2]. Nowadays low cost MEMS IMUs become popular for land vehicle navigation as they are available in small size with less power consumption, but accumulate the errors very fast and require regular calibration [3] [4]. The ultra-low cost MEMS IMUs also came into existence, their price is around 10 USD per piece. MEMS based IMUs also perform well if they integrate with GNSS receivers for mass-market application like navigation for land vehicle [5].

Integration of measurements of GPS or GLONASS receivers with IMU, and its performances evaluated and reported in the literature. Several GPS/GLONASS integrated with IMU are also available commercially. As the total no of satellites of NavIC/IRNSS is limited to seven at present as compared to 24 satellites for GPS and GLONASS, there is more probability for non-availability of NavIC solution as compared to GPS/GLONASS solution due to obstruction of signals. However, in the open literature, integration of NavIC/IRNSS signals with IMU is not found. Hence, it is proposed to evaluate the performance of the loosely coupled integration of low cost IMU and NavIC receiver. The performance of the loosely coupled integration included with ZVU during GNSS outages is comparable with open sky environment without obstruction of GNSS signals.

The rest of the paper structured as follows, section 2 detail the mathematical models of INS and theory of NavIC receiver. The static analysis of low cost IMU explained in section 3. Section 4 presents the navigation filer and GNSS/INS integration algorithm. Section 5 shows the experimental setup and result analysis of integrated system with real datasets. Finally concluded the remarks in the section 6.

2. INTEGRATION SENSORS

Various sensors are available for land vehicle navigation, but we choose only GNSS and INS for this work due to their complementary features. The concept of INS and GNSS are given in this section.

2.1 Inertial Navigational System (INS)

INS is self-contained navigation system that provides information about Position, Velocity and Attitude (PVA) of a vehicle based on the measurements obtained using inertial sensors and applying the dead reckoning (DR) principle [3] [6] [7]. INS is a combination of IMU and Navigation Processor as shown in Figure 1. IMU include with three accelerometers and three gyroscopes to provide 3D acceleration specific force f_b and angular rates ω_b respectively [8]. Navigation processor compute the PVA solution by using acceleration and angular rates with the equations of mechanization for given specific initial conditions.

As a dead reckoning device IMU require initial attitude angles (roll, pitch, and yaw) with respect to body of the vehicle, this process is called as initial alignment of IMU. General assumption for land vehicle navigation is, the travel direction of vehicle is same as x-axis (forward) of IMU. The initial alignment is done in two modes, static and dynamic. These modes are applied to IMU based on the precision or quality of IMU. For low cost IMUs static mode is not suitable, because the error/noise levels are more. So the dynamic mode of alignment is best suitable for low cost MEMS based IMU.

2.1.1 IMU

The accelerometer and gyroscope output measurement models of IMU are explained in this section

Accelerometer

An accelerometer triad measures the specific force of the IMU body with respect to inertial frame in body axis, the vector $\tilde{f}$. The measurement model is

$$\tilde{f} = f_{ib}^{b} + \eta_f + \eta_{f\delta b} + b_f \tag{1}$$

Where, f_{ib}^{b} is the ideal accelerometer output, η_f is the random noise of accelerometer measurements, modelled as Velocity Random Walk (VRW) with $\eta_f = \mathcal{N}(0,\sigma_f^2)$, variance $\sigma_f^2 = [\sigma_{fx}^2, \sigma_{fy}^2, \sigma_{fz}^2]^T$. $\eta_{f\delta b}$ related to dynamic bias and b_f refers static bias.

Gyroscope

Gyroscopes provide angular rate $\tilde{\omega}$ of the IMU body with respect to inertial frame.

$$\widetilde{\omega} = \omega_{ib}^{b} + \eta_g + \eta_{g\delta b} + b_g \tag{2}$$

Where ω_{ib}^{b} is the ideal angular rate of body frame, η_g is the random noise modelled as Angle Random Walk (ARW) with $\eta_g = \mathcal{N}(0, \sigma_g^2)$, variance $\sigma_g^2 = [\sigma_{gx}^2, \sigma_{gy}^2, \sigma_{fgz}^2]^T$. $\eta_{g\delta b}$ related to dynamic bias and b_g is static bias.

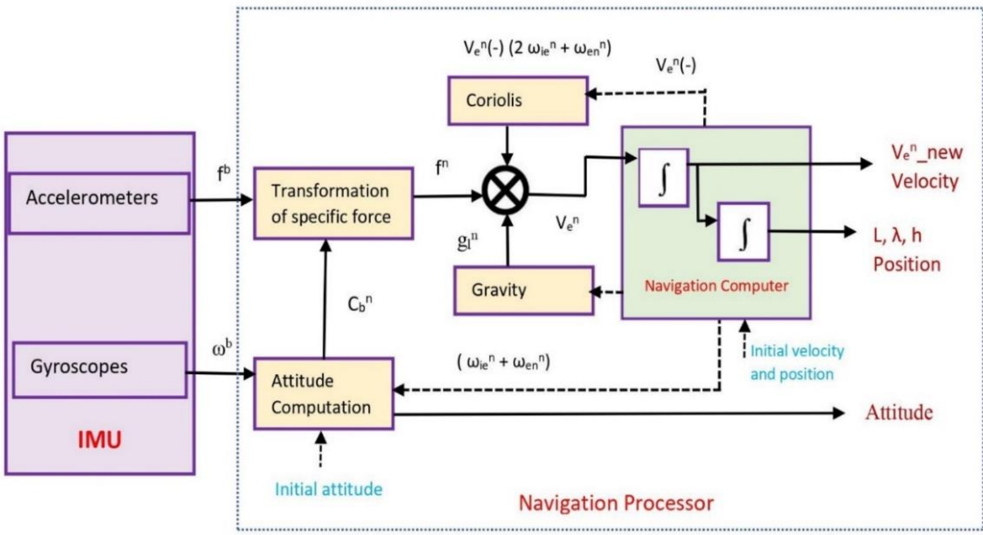


Figure 1: Block diagram of Inertial Navigation System

2.1.2 Navigation Processor

This unit convert the output of IMU i.e. specific force f_{ib}^{b} and angular rate ω_{ib}^{b} into position, velocity and attitude, this process is called as INS mechanization. It uses initial values and iterate the output recursively with DR technique. The mechanization equations are given below.

Attitude update

The corrected angulate rate ω_{nb}^{b} in navigation frame in (3)

$$\omega_{nb}^{b} = \omega_{ib}^{b} - C_n^b \ (\omega_{ie}^{n} + \omega_{en}^{n}) \tag{3}$$

Where ω_{ie}^{n} and ω_{en}^{n} are the turn rate and transport rate of earth in navigation frame, C_n^b is the coordinate transformation matrix to transform the navigation frame to body frame.

Velocity update

The velocity update in navigation processor is given as (4)

$$V_e^n = f_n - V_e^n(-)\,(2\,\omega_{ie}^{n} + \omega_{en}^{n}) + g_l^n \tag{4}$$

Where V_e^n is velocity in navigation frame, calculated using ω_{ie}^{n}, ω_{en}^{n};
f_n is the specific force in navigation frame,
g_l^n is the local gravity in navigation frame and
Δt is update rate

New velocity update using (5)

$$V_e^n\_new = V_e^n(-) + \Delta t * V_e^n \tag{5}$$

Position update

Position parameters are latitude L, longitude λ and height h are updated using (6)

$$
\begin{aligned}
&L(+) = L(-) + \Delta t * VN/(R_M+h)\\
&\lambda(+) = \lambda(-) + \Delta t * (V_E/(\cos(L) * (R_N+h))\\
&h(+) = h(-) - \Delta t * V_D
\end{aligned}
\tag{6}
$$

Where L (+), λ (+), h (+) are the updated position parameters using previous position parameters L (-), λ (-), h (-), updated velocity parameter V_e^n_new i.e., V_N, V_E, V_D; R_M is Meridian radius and R_N is Normal radius curvature of the Earth.

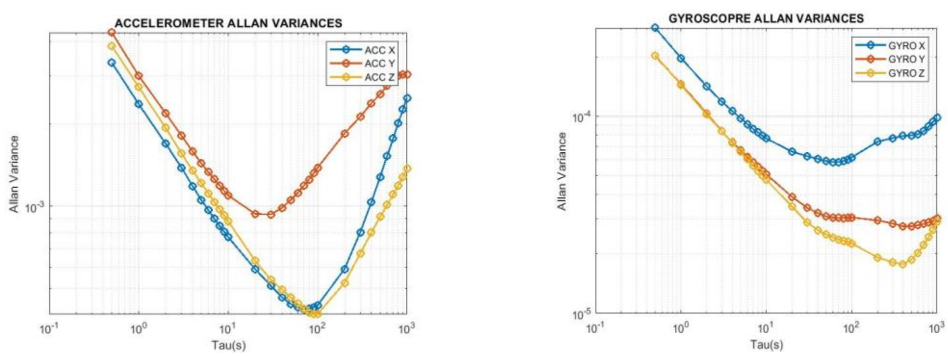
2.2 GNSS

Satellite navigation system includes global navigation satellite systems GPS, GLONASS, Galileo and BeiDou and regional navigation satellite systems NavIC/IRNSS and QZSS. In this project, mainly focused on the regional navigation system developed by India, NavIC/IRNSS and its integration with the low cost MEMS IMU. NavIC is also called as Indian Regional Navigational Satellite System (IRNSS). It is a regional navigational satellite system developed by ISRO, it covering only in India and surroundings covering upto1500kms. NavIC space segment consist of seven satellites with three in the Geostationary Orbits (GEO) and four in the Geosynchronous Orbits (GSO). NavIC provides two services Standard Positing Service (SPS) for civilian users and Restricted Service (RS) for authorized users. These signals are transmitted over two frequencies L5-1176.45MHz and S- 2492.028MHz.

As we are interested to compare the integration of NavIC or GPS with low cost IMU, a GNSS receiver having capability to compute the Position, Velocity and Time (PVT) using NavIC or GPS signals or together i.e. Accord's IRNSS/GPS/SBAS (IGS) receiver which is readily available at NERTU is used in this project. This receiver can compute the PVT only using GPS L1 band C/A signals or only using NavIC L5 band C/A signals, or only using NavIC S band C/A signals. It can also compute the PVT with the combination of any two. As per the specifications of the IGS receiver, it provides position accuracy up to 10m.

3. COMPUTATION OF ALLAN VARIANCE

The noise in the low cost MEMS based IMUs can be divided into low and high frequency noises. The characteristics or the parameters to describe these noises are required to implement the Extended Kalman Filter (EKF) for integration of GNSS and INS. The Allan Variance (AV) method is widely used technique to analyse the error characteristics of inertial sensors. AV is originally developed by D.W Allan to study the frequency stability of oscillators in time domain [9]. It is used to determine the features of random process, with this when the sensor noise increases, it helps to identify the noise terms in measured data. The thorough theoretical concepts of AV found in literature [10] [11]. The static data is collected from BMI160 IMU, which is included in the U-Blox, EVK-M8U device. It is a MEMS based and very low cost IMU. The device is setup on the table in fixed position and the data logged for 3hrs in the Navigation lab of NERTU. The AV is computed using NaveGo open source MATLAB toolbox [12] [5], the AV plots of both accelerometers and gyroscopes as shown in below Figure 2. In this work, we computed different noise parameters of accelerometers and gyroscopes, Random Walk (RW), Bias Instability (BI), Static Bias (SB) and Correlation Time, which are required for EKF. All these parameters are calculated in terms of SI units as shown in Table 1. It is also observed that the typical values of the Velocity Random Walk(VRW) of accelerometers and Angle Random Walk(ARW) of gyroscopes mentioned in the data sheet of BMI160 [13] as 180-300μg/√Hz and 0.007º/s/√Hz respectively, are matching with the computed values. By observing the computed values, the BMI160 IMU comes into the automotive grade MEMS sensor category.



(a) (b)

Figure 2: Allan variance of (a) 3-axis Accelerometers and (b) 3-axis Gyroscopes

Table 1: Noise profile of BMI160 IMU from Allan variance analysis

Sensor	**Random Walk** ($m/s^2/\sqrt{Hz}$) ($rad/s/\sqrt{Hz}$)	**Static Bias** (m/s^2) (rad/s)	**Dynamic Bias/ Bias Instability** (m/s^2) (rad/s)	**Correlation Time** (s)
Acc X	2.3578E-03	1.6025E-01	4.2053E-04	70
Acc Y	2.9933E-03	-3.2875E-02	9.3417E-04	30
Acc Z	2.7215E-03	9.7030	4.0289E-04	90
Gyro X	1.9698E-04	-3.7042E-03	5.8505E-05	60
Gyro Y	1.4523E-04	7.5806E-03	2.7580E-05	400
Gyro Z	1.4384E-04	-4.8822E-03	1.7760E-05	400

4. GNSS/INS INTEGRATION SYSTEM

GNSS and INS are complementary systems. The accuracy of GNSS system is consistent and will not increase with time, but there is a possibility of loss of navigation solution due to loss of signals. The accuracy of the INS system will degrade with time, but the navigation solution is always available. The GNSS/INS integration system compares the INS solution with the outputs of GNSS receiver and estimates the corrections by using the navigation filter, which provides the PVA solution. Therefore the GNSS/INS integration system provides continues and reliable navigation solution in any environments. There are different approaches to integrate GNSS and INS. Mainly they differ by depth of output data shared by each distinct system and these are loosely coupled, necessitate at least four satellites to be visible for continues positioning. In the tightly coupled integration, the INS output is combined with pseudo ranges and range rates of GNSS, in the navigation filter, and aiding information fed back to both systems. This is complex system, but it provides continues solution even the visibility of satellites are less than four [14] [15]. In the ultra-tightly coupled integration, the IMU measurements are used in the tracking loops of GNSS receiver to correct the carrier phase and code phase values, or to upgrade the carrier and code phase values as and when the GNSS signals are interrupted. Of course biases of INS also corrected in the ultra-tightly coupled system. This is very complicated system because it essential to access the receiver firmware, GNSS and INS no longer work independently, always aiding to each other in ultra-tightly coupled system.

In this work, we have implemented the loosely coupled integration, to integrate IMU and NavIC using 15 state-Kalman Filter (KF). It is the standard estimation filter used as a navigation filter for GNSS/INS integration. Generally, the outputs and dynamics of GNSS and INS are nonlinear in nature, hence to linearize the nonlinear signals the best suitable method is EKF [16] [17]. The EKF have primarily two steps, one is time update step and the other is measurement update step, the equations of EKF as shown in Figure 3. Where $\hat{x}_k$ and P_k are state vector and error covariance matrix respectively, Φ_k is the state transition matrix, Q_k and R_k are the process and observation covariance matrices, H_k is observation matrix, Z_k is the innovation vector and K_k is Kalman gain.

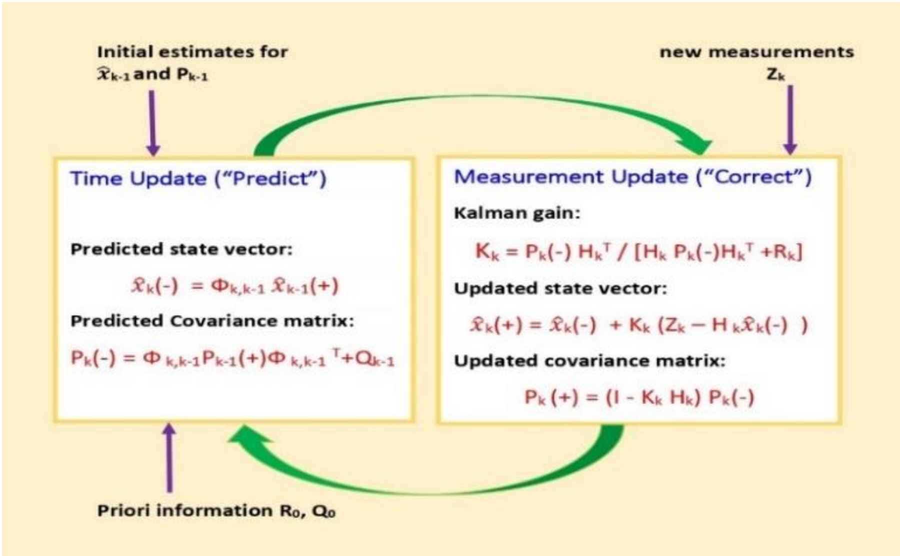


Figure 3: Block diagram of Extended Kalman Filter

The detailed equations and models of EKF for loosely coupled integration stated in [18] [19]. The flow chart of loosely coupled GNSS/INS integration algorithm is presented in Figure 4. First step is to initialize the attitude, velocity and position of INS, and then initialize the EKF parameters. Second step is INS mechanization, it updates PVA, next is to check the condition for ZVU, if zero velocity occurs it executes ZVU. Then check for GNSS receiver data whether it is available or not, if it is available it executes the EKF and updates the PVA and accelerometer and gyro biases, otherwise INS mechanization loop executes until GNSS data is available for integration. This total process executes until end of data.

Zero Velocity Update (ZVU):

If the land vehicle is stationary, the ZVUs calibrate the INS in the degraded signal environments of GNSS in urban areas. The stationary condition of the land vehicle tested with the estimated horizontal velocity in contrast to the threshold value, if the estimated velocity is below the threshold value then apply the ZVUs. The threshold value is based on the quality of IMU and for the present MEMS based IMU the threshold value is taken as 0.5m/s [3] [20].

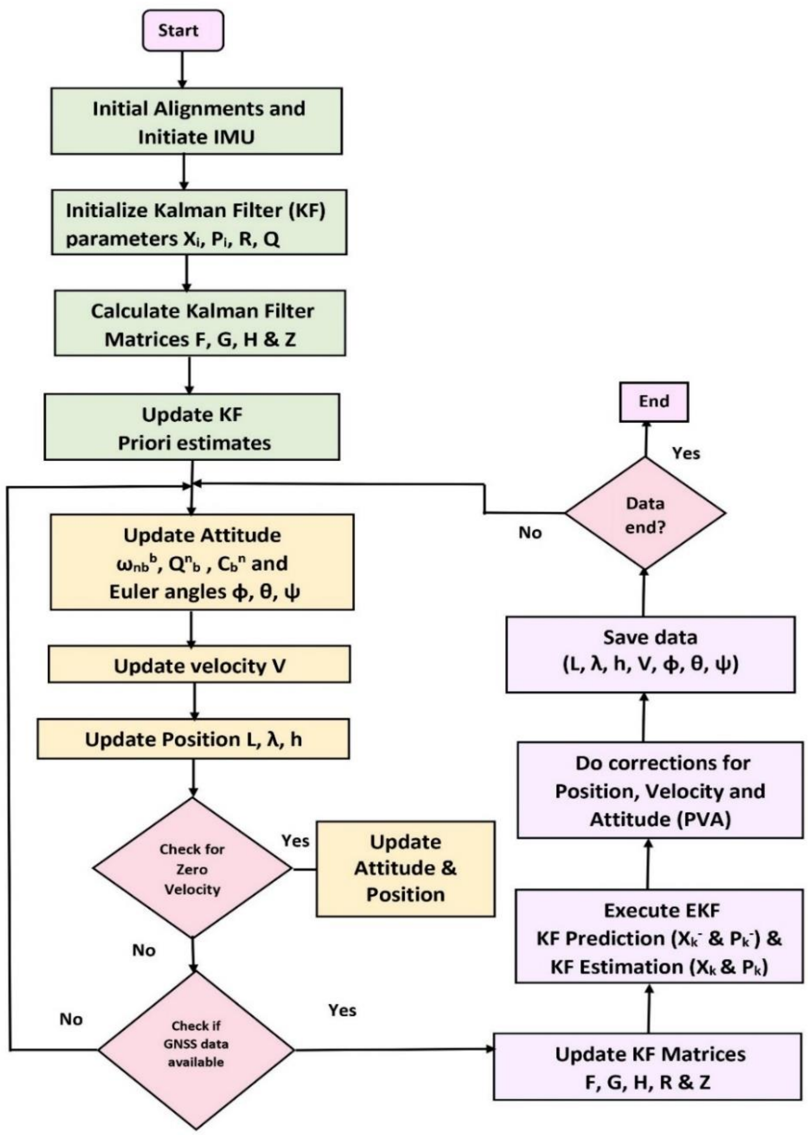


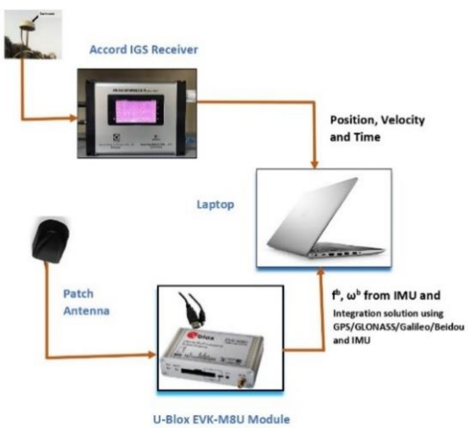
Figure 4: Flow chart for loosely coupled GNSS/INS Integration

5. EXPERIMENTAL RESULTS

5.1 Test Set-up

In the experiment, dynamic data of a land vehicle is collected at surroundings of the Osmania University, in the Hyderabad city of India, i.e. in the urban environment. The test set-up and moving vehicle is shown in Figure 5, which includes IGS receiver and U-Blox, EVK-M8U device. Input command, POSSEL will be used to choose the position computation using any of the three different modes; they are 1) NavIC 2) GPS and 3) NavIC+ GPS. The EVK-M8U is a dead reckoning device, it include both IMU and GNSS (GPS, Galileo, GLONASS and BeiDou). It provides raw IMU data as well as GNSS/INS Integrated output. This system is used as a reference system for this experiment. Raw IMU data and PVT solution of IGS is used for assessing the proposed integration. For initial alignment, IMU is placed on the vehicle in the forward (x- axis) direction i.e., matching with the moving direction of the vehicle. The vehicle has been driven at an average speed of 30kmph in the open sky condition to initialize the IMU for dynamic case. Data is collected from IGS receiver and IMU individually and simultaneously by installing EVK-M8U and IGS receiver in the vehicle as shown Figure 5 (a & b). Three trials were carried out choosing three modes of IGS receiver. In each trail or mode, almost same trajectory is followed. The slight deviation is either left/right/slow/fast due to traffic on the road.

Reference trajectory data is plotted in the google maps using U-center application as shown in Figure 6. The vehicle is travelled in urban area from point A to point B; it includes metro station, tall buildings and trees near roadside. Yellow circle represents the metro rail station. The number of GPS and NavIC visible satellites and the corresponding sky plot as observed using IGS receiver is given in Figure 7. The maximum and minimum number of visible satellites in these three modes are 5 and 0 for NavIC only, 10 and 2 for GPS only, 15 and 3 for NavIC+GPS mode respectively. This can be observed graphically in the Figure 7(b).



(a) (b)

Figure 5: Test Setup (a) Data collection setup in the vehicle (b) Data collection vehicle

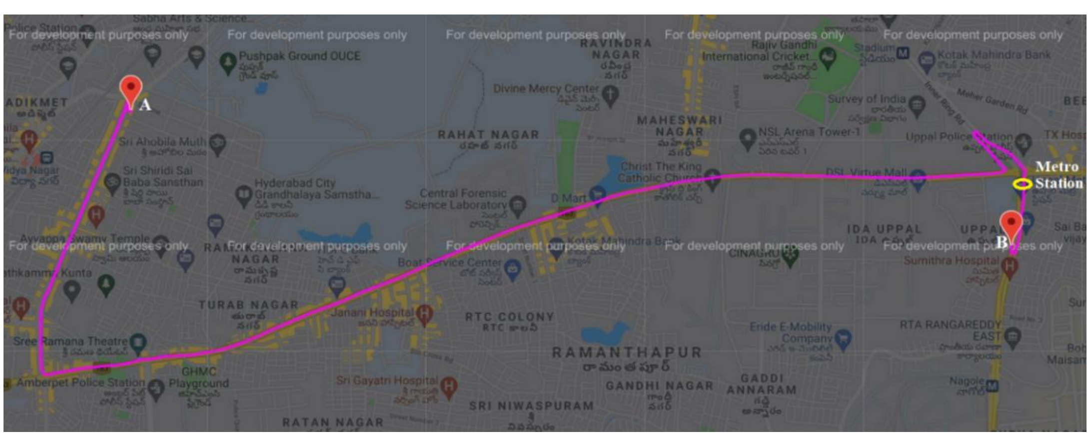
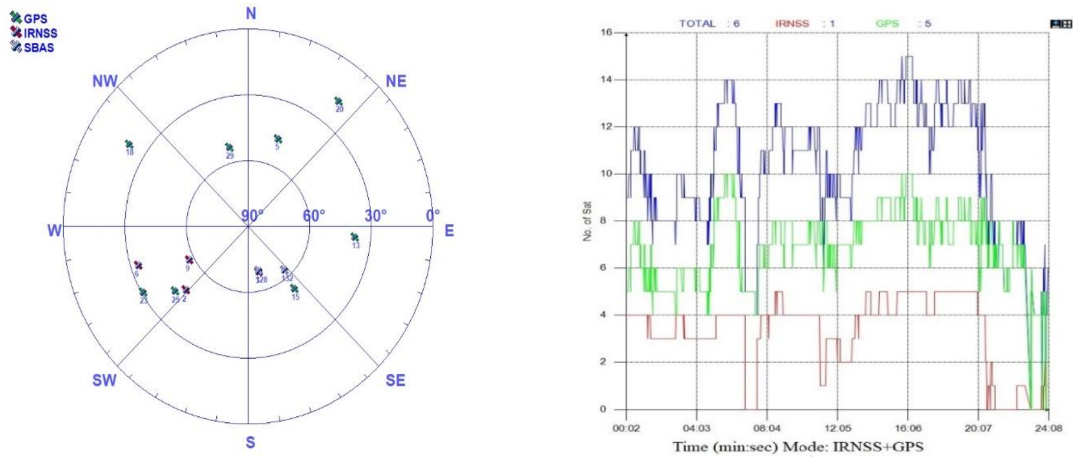


Figure 6: Trajectory of collected data in google map in U-center



(a) (b)

Figure 7: The Visibility of satellites in IGS receiver a) Sky Plot b) No of Satellites in NavIC+GPS mode

5.2 Result Analysis

The integration of low cost INS with GNSS is simulated in the post-processing mode. The results for the loosely coupled integration are analysed for three modes, they are 1) NavIC/INS Integration 2) GPS/INS Integration 3) NavIC+ GPS/INS Integration. The integrated navigation solution obtained in these three modes are analysed using statistical positional accuracy measures.

5.2.1 NavIC/INS Integration

In NavIC mode of IGS receiver, loosely coupled integration solution of NavIC/INS is compared with the reference solution as shown in Figure 8. Four outages are observed and these outages are indicated in the plot using numbers 1, 2, 3 and 4. In outage-1, the integration solution is deviated from the reference system; in outage-2 integration, solution is not much deviated for the straight path. Outage-3 occurs under the metro rail station with more outage period and the integration solution much deviated from the reference system. The integration solution almost follows the reference system in Outage-4. Quantitative statistical analysis is given for three modes together in the below section.

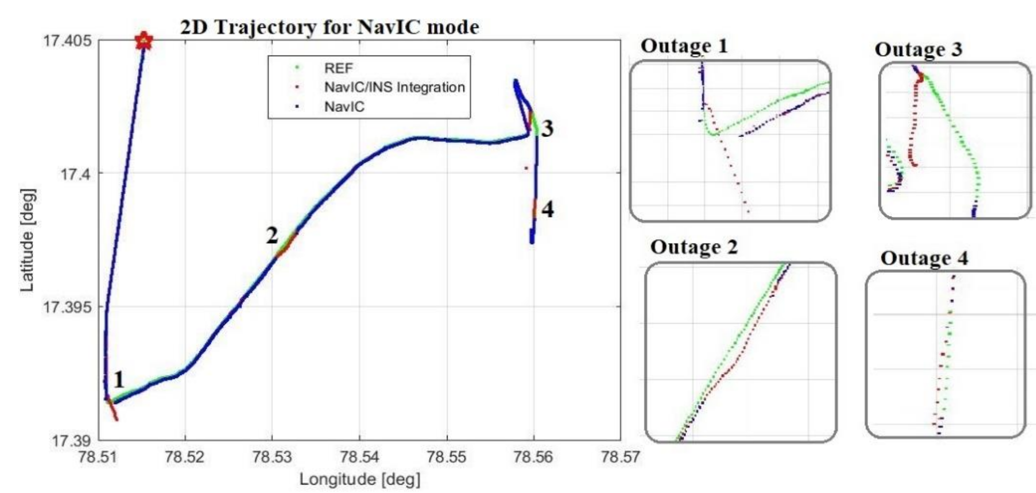


Figure 8: Trajectory obtained using NavIC/INS integration

5.2.2 GPS/INS Integration

In GPS mode of IGS receiver, three outages are occurred with small periods compared with the NavIC mode. The GPS/INS integration solution is plotted with respect to GPS and reference solution is shown in Figure 9. The Outage-1 is very small period and it exactly follows the reference system. Outage-2 is observed under the metro rail station, the integration solution is deviated from the reference solution. In outage-3, the integration solution is more deviated from the reference solution

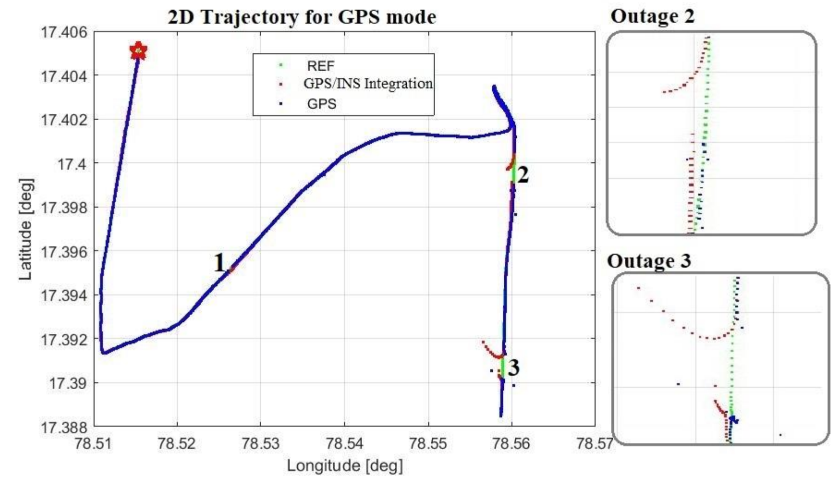


Figure 9: Trajectory obtained using GPS/ INS integration

5.2.3 NavIC+GPS/INS Integration

In NavIC+GPS mode of operation, three outages are observed in IGS receiver with small durations. The integration solution of NavIC+GPS/INS is plotted in Figure 10. Outage-1 is observed under the metro rail station, the integration solution smoothly follows the reference solution. The Outage-2 is very small period and it exactly follows the reference system. Outage-3 is also small period but the integration solution is deviated from reference solution.

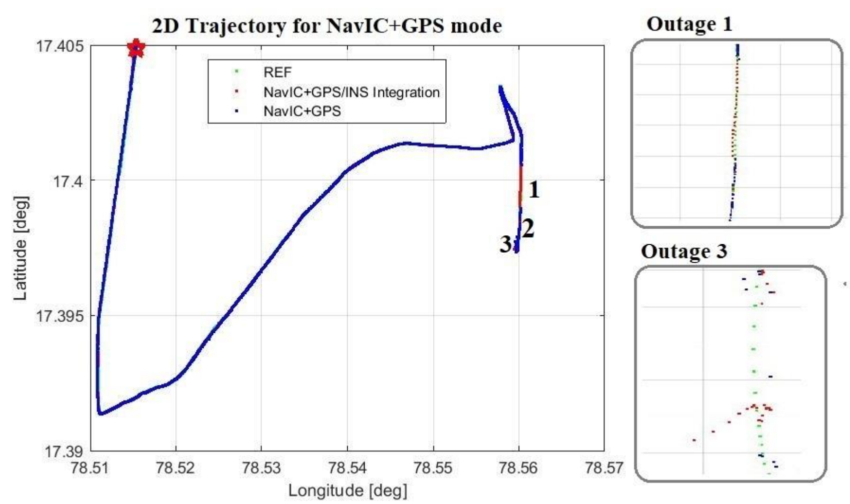
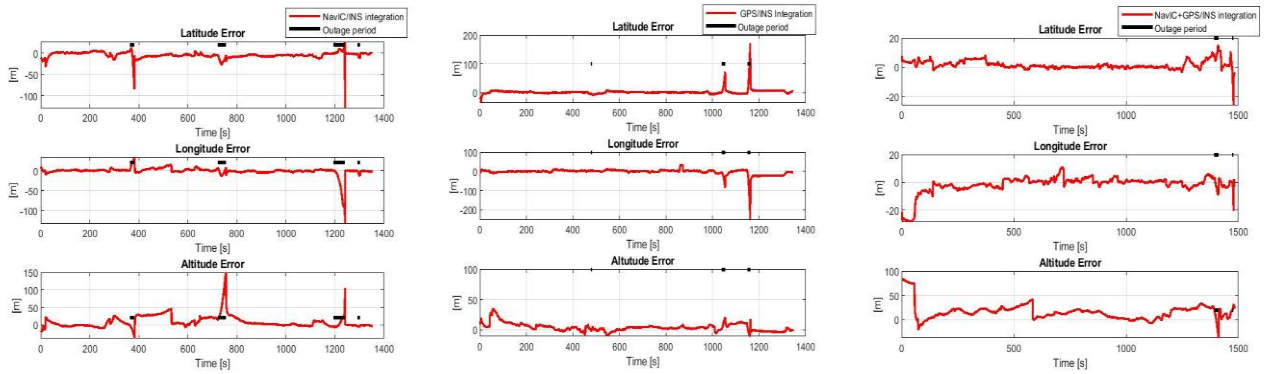


Figure 10: Trajectory obtained using NavIC+GPS /INS integration

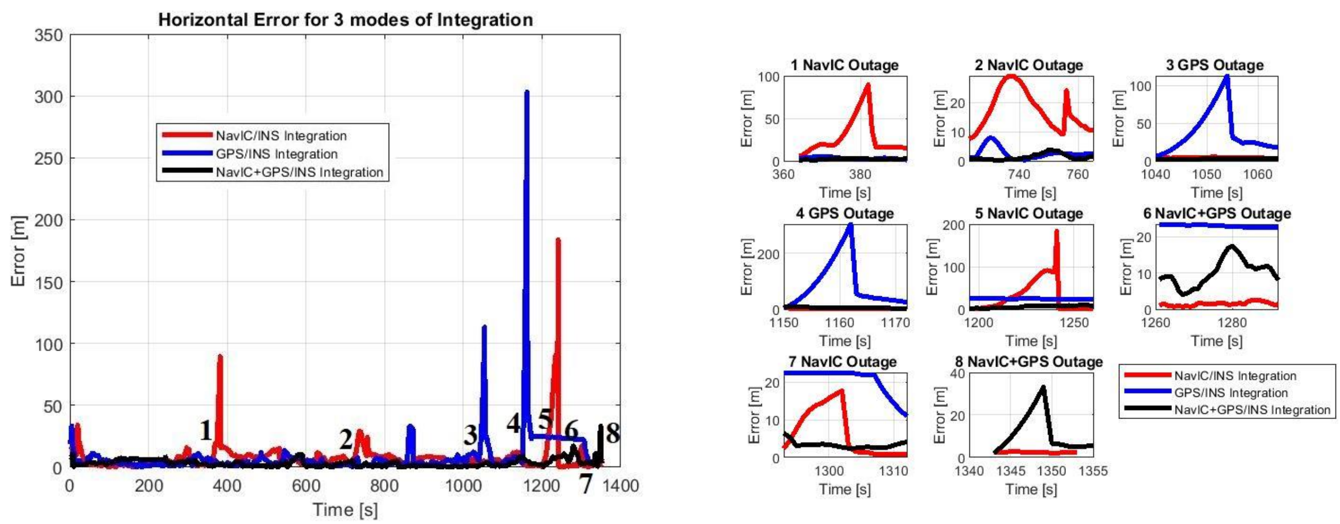
5.2.4 Comparison Results:

For the low cost MEMS based IMU, the errors are accumulated more with the time. During the outage period, there is no support from the GNSS signals. Hence, the integration solution with low cost IMU is rapidly deviated from the original path. The position error in the longitude, latitude and altitude for three modes of integration with respect to reference system is plotted and the outage period is represented with black line in Figure 11- (a), (b), (c). The position errors of NavIC/INS and GPS/INS integrations are high for the outage period, compared to NavIC+GPS/INS integration. The horizontal position errors of three modes of integration solutions are plotted in Figure 12(a) and each outage period corresponding to this plot is shown individually in Figure 12(b). The NavIC+GPS /INS integration solution provides an horizontal error of about 33m during the outage period, whereas horizontal error is going up to 183m for NavIC/INS and 303m for GPS/INS, which can be observed in Table 2.



(a) (b) (c)

Figure 11: Plots of position errors for (a) NavIC/INS (b) GPS/INS (c) NavIC+GPS/INS Integrations



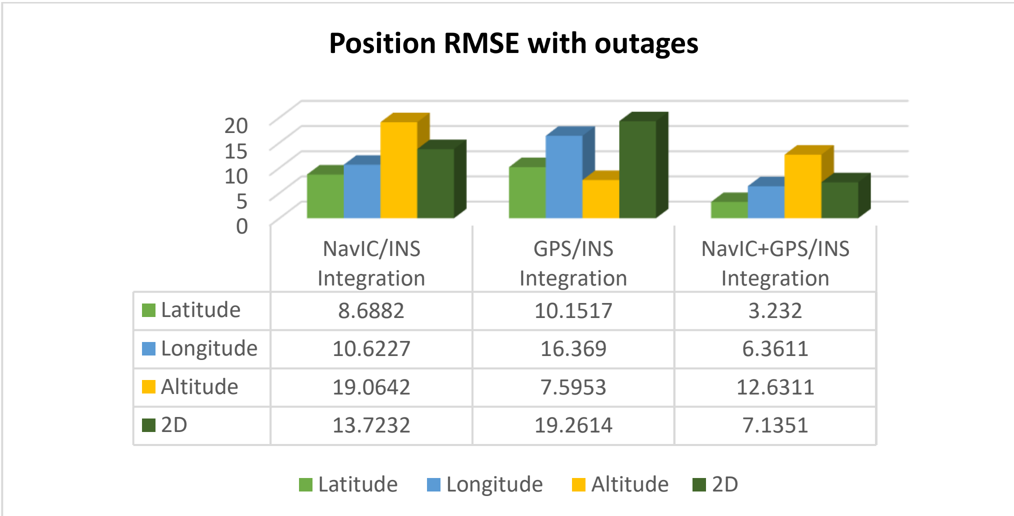
(a) (b)

Figure 12: Horizontal position error for (a) Integration of INS with 3 modes (b) All outages in 3 modes

Table 2: Signal outages and horizontal error peaks of 3 modes of Integration

	NavIC/INS Integration		GPS/INS Integration		NavIC+GPS/INS Integration	
	Outage Period (s)	**Horizontal Error Peak(m)**	**Outage Period (s)**	**Horizontal Error Peak(m)**	**Outage Period (s)**	**Horizontal Error Peak(m)**
Outage 1	19	89.4853	5	9.8893	22	17.4175
Outage 2	33	28.8601	15	113.1393	2	10.8677
Outage 3	46	183.6682	13	303.1114	7	33.1936
Outage 4	10	17.7114				

The Root Mean Square Error (RMSE) of three integrations are presented in Figure 13, with respect to reference system for the complete trajectory. It can be observed that the NavIC+GPS/INS system gives relatively better 2D RMSE over other integration systems.

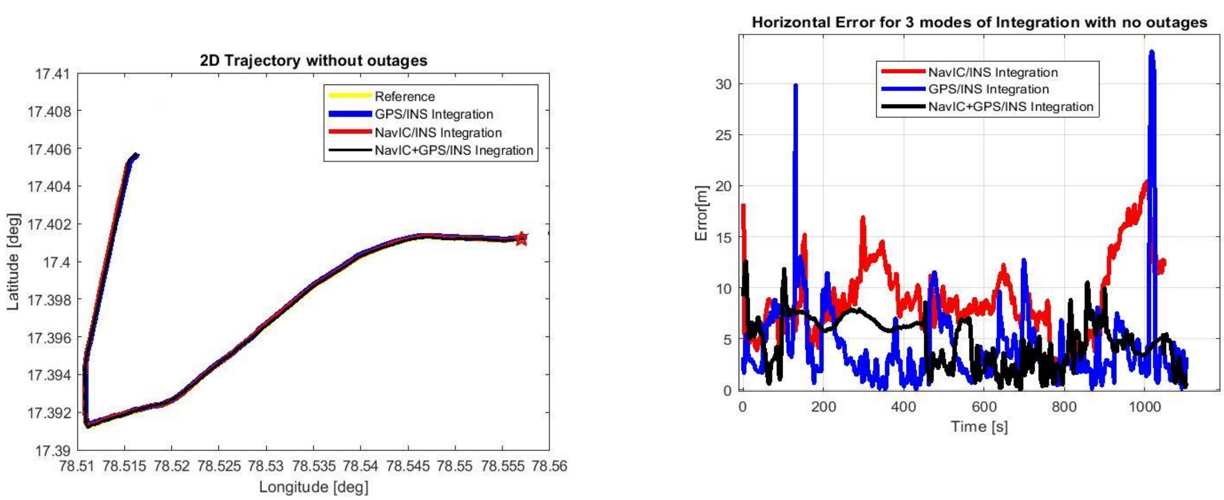


	NavIC/INS Integration	GPS/INS Integration	NavIC+GPS/INS Integration
Latitude	8.6882	10.1517	3.232
Longitude	10.6227	16.369	6.3611
Altitude	19.0642	7.5953	12.6311
2D	13.7232	19.2614	7.1351

Figure 13: RMSE for three modes of Integration with outages

5.2.5 Comparison of three modes without outages:

Comparison of integration of INS with the NavIC, GPS and NavIC+GPS modes is also analysed. The trajectory for the three modes of integration is plotted in Figure 14(a); star indicates starting point in the trajectory. There is no deviation observed in the three modes of integration solutions. The horizontal position error of three modes of integrations with no outages is plotted in Figure 14(b). The horizontal position accuracy of NavIC/INS has gone up to 22m, and for GPS/INS integration the accuracy is 34m. However, the accuracy for NavIC+GPS/INS integration is 15m. The RMSE for three modes of integration are calculated and plotted in Figure 15. The mean square error for GPS/INS integration is less than NavIC/INS integration. However, the reason for two peaks with horizontal error more than 15m is yet to be analysed. By observing the latitude, longitude, altitude and 2D RMSE for the combined system i.e., NavIC+GPS/INS integration provides better accuracy of approximately less than 6m, as compared with the individual NavIC and GPS integration systems.



(a) (b)

Figure 14: Plots for 3 modes of integration without outages (a) Trajectory (b) Horizontal error

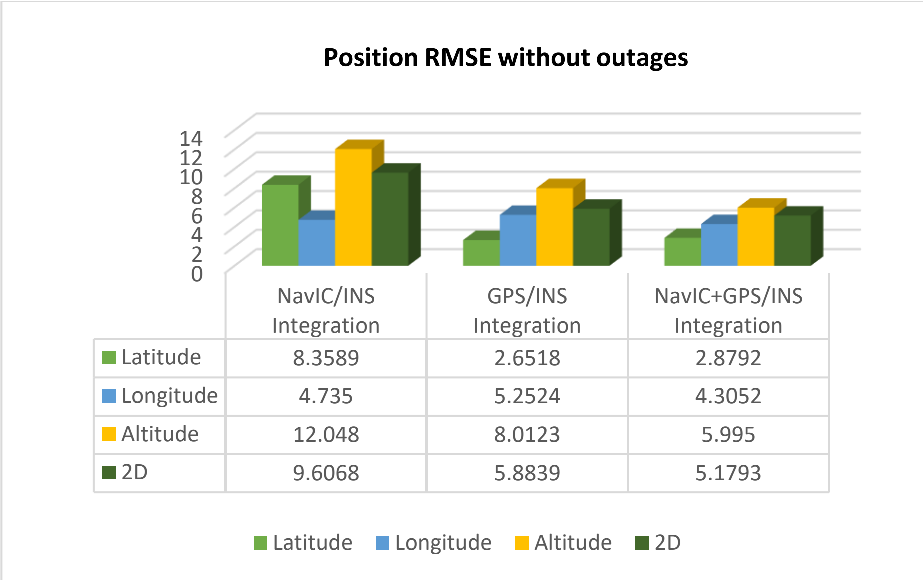


Figure 15: RMSE for three modes of integrations without outages

6. CONCLUSION

Integration of NavIC or GPS or NavIC+GPS with low-cost MEMS based IMU is implemented in this paper. Their performance in terms of horizontal position accuracy and RMSE are evaluated in urban area with and without outages. The performance of NavIC+GPS/INS system gives better 2D position accuracy about 7.13m with outages as compared with the individual NavIC/INS and GPS/INS systems with 13.72m and 19.26m respectively. Similarly the performance of NavIC+GPS/INS system gives better 2D position accuracy about 5.17m for no outages as compared with the individual NavIC/INS and GPS/INS systems with 9.6m and 5.88m respectively. By observing, the horizontal position accuracy of three integrations the low cost MEMS based IMU can withstand up to 30 seconds of outage up to 30m accuracy. The integration solution of low cost IMU with multi constellation receiver (NavIC+GPS) provides best performance than the single (NavIC or GPS) constellation receiver. Hence, the integration of low cost automotive grade IMU with the multi constellation GNSS receiver will improve the performance of the INS.

FUTURE SCOPE

The preliminary work on integration of low cost MEMS based IMU and NavIC is presented. The difference in the accuracy with different integrations with respect to horizontal position, the growth of error during outage period needs to be analysed for various aspects like path (turning of road or straight road), time (outage period), GNSS system (DOP or position accuracy) and many outages with in short duration. As a part of future work, to improve the accuracy with low cost MEMS, another navigation sources could be used to aid the present system. Tightly coupled integration of NavIC and MEMS based IMU should be analysed if we meet the accuracy for normal outages in the dense urban area.

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