Integration of INS-GPS-GSM for compact and low power application with increased efficiency

BALACHANDAR T,
M.E. Communication Systems,
Loyola Institute of Technology,
Chennai, India.
vinobala90@gmail.com

MRS.S.UMA MAHESWARI,
Assistant Professor, ECE Department,
Loyola Institute of Technology,
Chennai, India.
umatraj@gmail.com

Abstract- This project proposes a design for combined INS-GPS system for compact and low power applications. The existing system uses MEMS (micro electro mechanical system) based inertial sensors which are not accurate enough for INS (Inertial navigation system). MEMS based system was costly and accuracy is also less when compared to INS-GPS SYSTEM. The INS system is mainly used for aerospace applications to locate the moving aircrafts and missile tracking. INS is a huge system and it is not applicable to mini aerial vehicles. So we are integrating INS system with GPS system for high accuracy and easy to implement in mini aerial vehicles. The system is currently available in commercial off-the- shelf hardware. It is not optimized for compact single supply low power requirements. The proposed system uses PIC (Peripheral Interface Controller) for inertial navigation solutions to calculate the position and velocity of moving objects with accuracy.

A field programmable gate array (FPGA) is used for creating an efficient interface of the GPS with PIC. Direct serial interface of GPS involve tedious processing overhead on the navigation processor. A universal asynchronous receiver transmitter (UART) and dual port random axis memory are included on the FPGA. The FPGA reduces the total chip count, resulting in compact system and low power consumption.

I. INTRODUCTION

For automatic machines, be it robots, aircraft or other autonomous vehicles, navigation is of utmost importance. Various systems are used in navigation of aircraft, viz. inertial navigation systems (INS), global positioning systems (GPS), air-data dead reckoning systems, radio navigation systems, Doppler heading reference systems, to name a few. Our interest lies in integrating both the INS and the GPS to provide the best possible estimate of the aircraft position in terms of the latitude, longitude and height above the surface of the earth.

The INS gives us the position, velocity and attitude of the aircraft but it is inundated with errors due to the fact that any small bias error can grow the error with time. Hence , an update or position fix is taken from the GPS and using a Kalman filter we can estimate the errors in both the INS and the GPS thus giving the user a better position information. Applications are not limited to aircraft alone. Although these integrated systems find extensive usage in airborne vehicles, they have also been used in the navigation of cars, ships and satellites. There are considerable advantages in developing this kind of a navigation system.As compared to the ones used earlier in terms of compactness and speed. Micro- gyroscopes and GPS chips can be integrated on a small board and can effectively give the position of the vehicle concerned. With the advent of MEMS technology, all this can be done at extremely high levels of accuracy and at lower costs.

Our aim is to develop the GPS-INS integrated system so that it can be implemented on real time hardware like a microcontroller or a digital signal processor. Even though high accuracy sensors like gyroscopes and accelerometers are available, their costs are on the higher side. Usage of low cost and low accuracy sensors may find application where high accuracy is not required. Initially the simulation of the whole navigation would be done on a computer, where given the initial state of the aircraft and regular updates from the sensors and the GPS, the program would return the estimated position of the aircraft. Eventually this simulated model would be implemented in real time hardware.

The tightly coupled INS/GPS uses the pseudorange and Doppler measurements from both GPS and INS. It can continue to provide useful navigation information in situations where fewer than four satellites are visible. The tightly coupled integration filter is also used for the error controls of INS aiding Doppler and the receiver clock drift, both of which are fed into the receiver tracking loops.

Development and implementation of INS aided receiver carrier tracking algorithm, which minimizes the phase tracking errors under weak signal and/or highly dynamic environments.

II. Inertial Navigation Systems

An Inertial Navigation System is an autonomous Dead Reckoning (DR) system that usually combines accelerometers and gyroscopes to provide position and velocity by measuring the accelerations and angular rates applied to the system's inertial frame. Other types of DR sensors may also be used in INS such as the compass, odometer, inclinometer, altimeter, etc. Unlike the GPS that requires external signals to provide positional information, INS is self-contained and immune to jamming and deception, regardless of the operational environment.

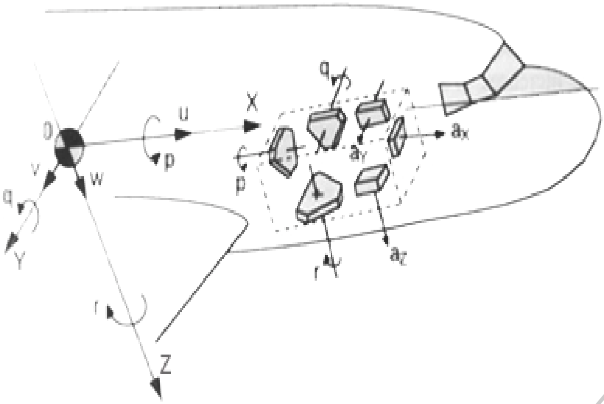

Figure.1. Orientation of axes

The INS consists of 3-axis gyroscopes which give the system computer the roll, pitch and yaw rates about the body axes as shown in figure.1.It also has-axis accelerometers which give the accelerations along the three body axes. There are two basic inertial mechanisms which are used to derive the Euler angles from the rate gyros, viz. stable platform and strap-down INS. We would be concerned with the strap-down INS where the gyros and accelerometers are 'strapped-down' to the aircraft body frame. The acceleration values from the accelerometers are then corrected for rotation of the earth and gravity to give the velocity and position of the aircraft.

Equations Of Motion

The orientation of an aircraft with respect to a fixed inertial frame of axes is defined by three Euler angles. The aircraft is imagined to be oriented parallel to the fixed reference frame of axes. A series of rotations bring it to the orientation about axes OX, OY and OZ, as shown in figure.2.

a. Clockwise rotation about the yaw axis, through the yaw (or heading) angle ϕ ,

b. Clockwise rotation about the pitch axis, through the pitch angle θ ,

c. Clockwise rotation about the roll axis, through the bank angle ϕ .

The relationship between the angular rates of roll, pitch and yaw, p, q, r (measured by the body mounted gyros), the Euler angles, ϕ , θ , ϕ and their rates, is given below.

$$\begin{bmatrix}\phi\\ \theta\\ \psi\end{bmatrix} = \begin{bmatrix}1 & \sin\phi\tan\theta & \cos\phi\tan\theta\\ 0 & \cos\phi & -\sin\phi\\ 0 & \sin\phi\sec\theta & \cos\phi\sec\theta\end{bmatrix}\begin{bmatrix}p\\ q\\ r\end{bmatrix} \quad (1)$$

By integration of the above equations we can derive the Euler angles using initial conditions of a known attitude at a given time. But, for pitch angles around ±90◦, the error becomes unbounded as tan θ tends to infinity. Quaternion algebra comes to the rescue here. We use four parameters, called the Euler parameters, that are related to the Euler angles as follows .

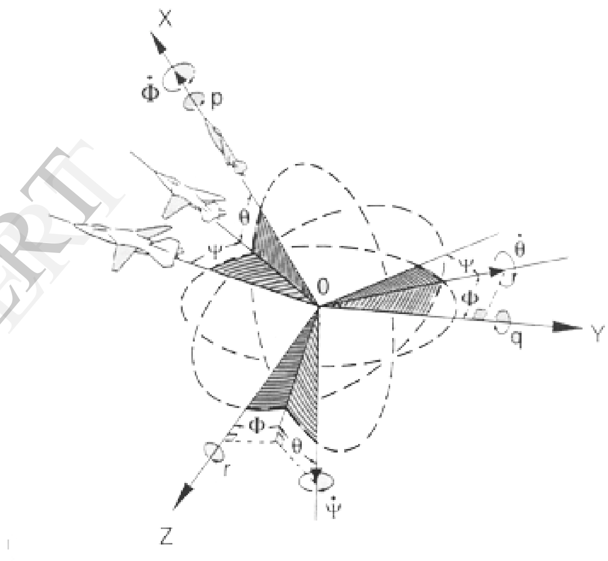

Figure.2.: Euler Angles

If e0 , e1, e2 , e3 were the four parameters then in terms of angular rates, we have

$$e_0 = -\frac{1}{2}(e_1 p + e_2 q + e_3 r) \quad (2)$$

$$e_1 = \frac{1}{2}(e_0 p + e_2 r - e_3 q) \quad (3)$$

$$e_2 = \frac{1}{2}(e_0 q + e_3 p - e_1 r) \quad (4)$$

$$e_3 = \frac{1}{2}(e_0 r + e_1 q - e_2 p) \quad (5)$$

with the parameters satisfying the following equation at all points of time.

$$e_0^2 + e_1^2 + e_2^2 + e_3^2 = 1 \quad (6)$$

The above equations can be used to generate the time history of the four parameters e0 , e1, e2 and e3 . The initial values of the Euler angles are given which are used to calculate the initial values of the four parameters using the following equations.

$$e_0 = \cos\frac{\psi}{2}\cos\frac{\theta}{2}\cos\frac{\phi}{2} + \sin\frac{\psi}{2}\sin\frac{\theta}{2}\sin\frac{\phi}{2} \qquad (7)$$

$$e_1 = \cos\frac{\psi}{2}\cos\frac{\theta}{2}\cos\frac{\phi}{2} - \sin\frac{\psi}{2}\sin\frac{\theta}{2}\sin\frac{\phi}{2} \qquad (8)$$

$$e_2 = \cos\frac{\psi}{2}\sin\frac{\theta}{2}\cos\frac{\phi}{2} + \sin\frac{\psi}{2}\cos\frac{\theta}{2}\sin\frac{\phi}{2} \qquad (9)$$

$$e_3 = -\cos\frac{\psi}{2}\sin\frac{\theta}{2}\sin\frac{\phi}{2} + \sin\frac{\psi}{2}\cos\frac{\theta}{2}\cos\frac{\phi}{2} \qquad (10)$$

Once we calculated the time history of the four parameters, we can calculate the Euler angles using the following equations.

$$\theta = \sin^{-1}[2(e_1 e_3 - e_0 e_2)] \qquad (11)$$

$$\phi = \cos^{-1}\left[\frac{e_0^2 - e_1^2 - e_2^2 + e_3^2}{\sqrt{1-4(e_1 e_3 - e_0 e_2)^2}}\right]\operatorname{sign}[2(e_2 e_3 + e_0 e_1)]$$

$$\psi = \cos^{-1}\left[\frac{e_0^2 + e_1^2 - e_2^2 - e_3^2}{\sqrt{1-4(e_1 e_3 - e_0 e_2)^2}}\right]\operatorname{sign}[2(e_1 e_2 + e_0 e_3)]$$

We now have with us the attitude of the aircraft. To calculate the position we use the accelerations given by the accelerometers.

The accelerations (ax, ay and az) of the aircraft along the three body axes, as read by the accelerometers, are given by the equations . U , V , W and p, q, r are all available as states. If the acceleration due to gravity (g) model is supplied as a function of location around the earth, then U , V˙ and W can be calculated.

$$\dot{U} = a_x + Vr - Wq + g\sin\theta \qquad (14)$$

$$\dot{V} = a_y - Ur + Wp - g\cos\theta\sin\phi \qquad (15)$$

$$\dot{W} = a_z + Ur - Vq - g\cos\theta\cos\phi \qquad (16)$$

The earth is rotating in space at a rate Ω (15◦ per hour) around an axis South to North as shown in figure .3.

$$\Omega = \begin{bmatrix} \Omega\cos\lambda \\ 0 \\ -\Omega\sin\lambda \end{bmatrix} \qquad (17)$$

The motion of the vehicle at a constant height above the ground will induce an additional rotation given by

$$w' = \begin{bmatrix} \dot{\mu}\cos\lambda \\ -\dot{\lambda} \\ -\dot{\mu}\sin\lambda \end{bmatrix} \qquad (18)$$

the measured angular rates include Ω and ω′, we have the actual angular rates given by

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} p \\ q \\ r \end{bmatrix}_m - DCM[\Omega + w'] \qquad (19)$$

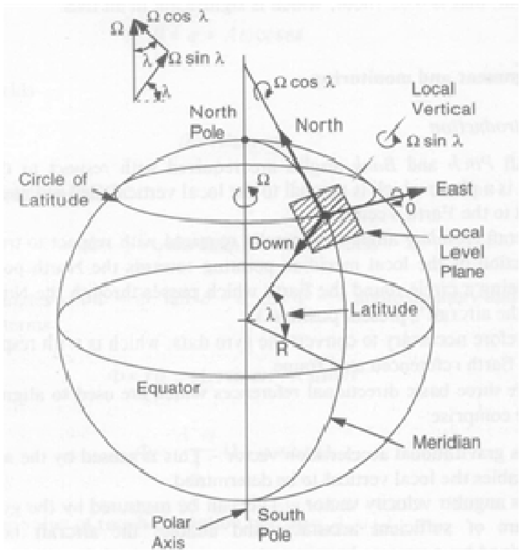

Figure .3: Local earth frame or Navigation frame

where DCM is the the direction cosine matrix or the transformation matrix, from the local earth or navigation frame to the body frame, given by equation µ is the rate of change of longitude and is the rate of change of latitude.

$$DCM = \begin{bmatrix} \cos\theta\cos\psi & \cos\theta\sin\psi & -\sin\theta \\ \sin\theta\sin\phi\cos\psi - \sin\psi\cos\phi & \sin\psi\sin\theta\sin\phi + \cos\psi\cos\phi & \sin\phi\cos\theta \\ \sin\theta\cos\phi\cos\psi + \sin\psi\sin\phi & \sin\phi\sin\theta\cos\phi - \cos\psi\sin\theta & \cos\phi\cos\theta \end{bmatrix}$$

U , V and W were integrated to calculate with the velocity components (U , V and W), which are then transformed using the direction cosine matrix to give velocity along North (VN), velocity along East (VE) and downward velocity (VD) in the navigation frame or local earth frame, as shown in figure .3.

$$\begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \end{bmatrix} = \begin{bmatrix} V_N \\ V_E \\ V_D \end{bmatrix} = DCM^T \begin{bmatrix} U \\ V \\ W \end{bmatrix} \qquad (20)$$

VN , VE and VD are then integrated to give distances moved along the navigation axes (X, Y, Z) on the surface of the earth. Let λ, µ and H denote the latitude, longitude and height of the aircraft at any instant, rate of change of latitude is given by

$$\dot{\lambda} = \frac{V_N}{R_e} \qquad (21)$$

and rate of change of longitude is given by

$$\dot{\mu} = \frac{V_E}{R_e\cos\lambda} \qquad (22)$$

where Re is the radius of the earth. The rate of change of altitude of the aircraft is given by

$$\dot{H} = -V_D \qquad (23)$$

The position of the aircraft in terms of latitude, longitude and altitude can be thus calculated using equations 22, 23 and 24.

Errors in INS:

Most INS errors are attributed to the inertial sensors (instrument errors). These are the residual errors exhibited by the installed gyros and accelerometers following calibration of the INS.

Errors in the accelerations and angular rates lead to steadily growing errors in position and velocity components of the aircraft, due to integration. These are called navigation errors.The errors are - three position errors, three velocity errors, two attitude errors and one heading error. If an unaided INS is used, these errors grow with time. It is for this reason that the INS is usually aided with either GPS, Doppler heading sensor or air-data dead reckoning systems. Gravity model can also cause some errors. The acceleration due to gravity varies from place to place along the earth and also with height. These errors have to be modeled accordingly.

Inertial sensors for strap down systems experience much higher rotation as compared to their gimbaled counterparts. Rotation introduces error mechanisms that require attitude rate-dependent error compensation.

2 Global Positioning System

GPS uses a one-way ranging technique from the GPS satellites that are also broadcasting their estimated positions. Signals from four satellites are used with the user generated replica signal and the relative phase is measured. Using triangulation the location of the receiver is fixed. Four unknowns can be determined using the four satellites and appropriate geometry : latitude, longitude, altitude and a correction to the user's clock. GPS constellation is shown in figure .4.

The GPS receiver coupled with the receiver computer returns elevation angle between the user and satellite, azimuth angle between the user and satellite, measured clockwise positive from the true north, geodetic latitude and longitude of the user.The GPS ranging signal is broadcast at two frequencies : a primary signal at 1575.42 MHz (L1) and a secondary broadcast at 1227.6 MHz (L2). Civilians use L1 frequency which has two modulations, viz. C/A or Clear Acquisition (or Coarse Acquistion) Code and P or Precise or Protected Code. C/A is unencrypted signal broadcast at a higher bandwidth and is available only on L1 . P code is more precise because it is broadcast at a higher bandwidth and is restricted for military use. The military operators can degrade the accuracy of the C/A code intentionally and this is known as Selective Availability. Ranging errors of the order of 100m can exist with Selective Availability.

There are six major causes of ranging errors : satellite ephemeris, satellite clock, ionospheric group delay, tropospheric group delay, multipath and receiver measurement errors, including software.

The primary role of GPS is to provide highly accurate position and velocity world-wide, based on range and range-rate measurements. GPS can be implemented in navigation as a fixing aid by being a part of an integrated navigation system, for example INS/GPS.

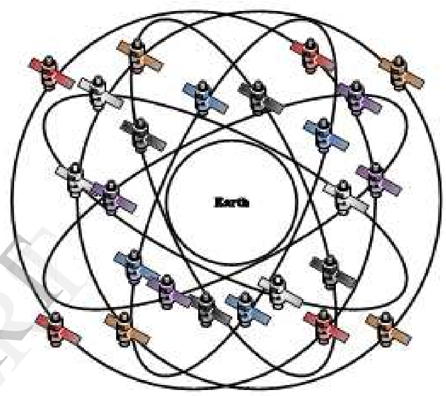

Figure .4. Illustration of GPS constellation

2.1 Errors In GPS

Ephemeris errors occur when the GPS message does not transmit the correct satellite location and this affects the ranging accuracy. These tend to grow with time from the last update from the control station. Satellite clock errors affect both C/A and P code users and leads to an error of 1-2m over 12hr updates . Measurement noise affects the position accuracy of GPS pseudo range absolute positioning by a few meters. The propagation of these errors into the position solution can be characterized by a quantity called Dilution of Precision (DOP) which expresses the geometry between the satellite and the receiver and is typically between 1 and 100. If the DOP is greater than 6, then the satellite geometry is not good.

Ionospheric and tropospheric delays are introduced due to the atmosphere and this leads to a phase lag in calculation of the pseudo range. These can be corrected with a dual-frequency P-code receivers. Multipath errors are caused by reflected signals entering the front end of the receiver and masking the correlation peak. These effects tend to be more prominent due to the presence of reflective surfaces, where 15m or more in ranging error can be found in some cases.

3. Global System For Mobile Communication

3.1 Definition

Global system for mobile communication (GSM) is a globally accepted standard for digital cellular communication. Global System for Mobile Communications, originally Group Spécial Mobile, is a standard set developed by the European Telecommunications Standards Institute (ETSI) to describe protocols for second generation (2G) digital cellular networks used by mobile phones.The GSM standard was developed as a replacement for first generation (1G) analog cellular networks, and originally described a digital, circuit switched network optimized for full duplex voice telephony. This was expanded over time to include data communications, first by circuit switched transport, then packet data transport via GPRS (General Packet Radio Services) and EDGE (Enhanced Data rates for GSM Evolution or EGPRS).

GSM is established in 1982 to create a common European mobile telephone standard that would formulate specifications for a pan-European mobile cellular radio system operating at 900 MHz.

3.2 The GSM Network

GSM provides recommendations, not requirements. The GSM specifications define the functions and interface requirements in detail but do not address the hardware. The reason for this is to limit the designers as little as possible but still to make it possible for the operators to buy equipment from different suppliers. The GSM network is divided into three major systems: the switching system (SS), the base station system (BSS), and the operation and support system (OSS). The basic GSM network elements are shown in figure .5

GSM having the following subsystems,

a. Mobile services switching center

b. Authentication center

c. Operations and maintenance center

d. Operation and support system

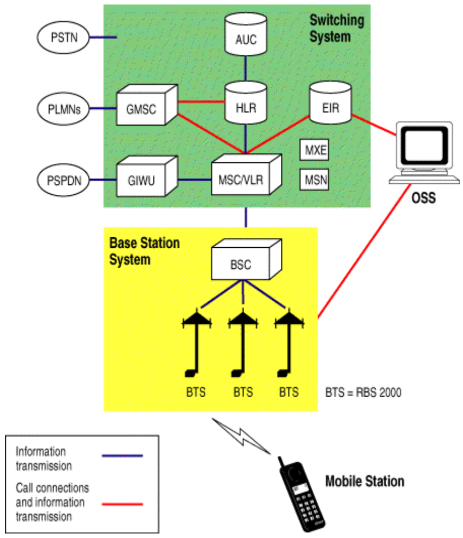

Fig .5 GSM Network Elements

PROPOSED SYSTEM

The proposed integrated system with a lightweight package providing the navigation system function is shown in Fig. 6. For better understanding, the system can be divided into two main blocks and their sub-blocks as below:

1) GPS and IMU data acquisition card (GIDAC)
   a) Analog signal acquisition
   b) GPS serial data acquisition.
2) Navigation Processor Card (NPC).

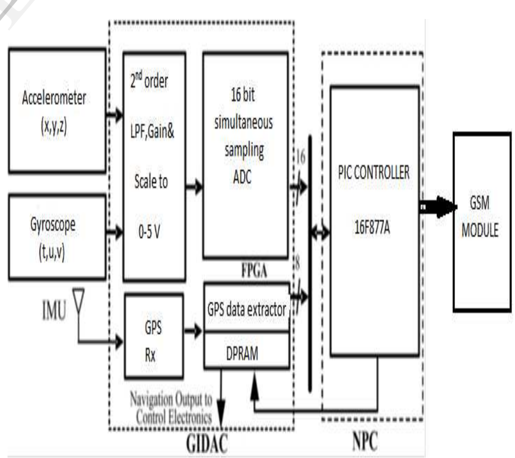

Fig..6. System architecture.

The proposed architecture is now explained in details.

1.GPS and IMU Data Acquisition Card

GIDAC consists of two parts. The first part is the analog signal acquisition block which processes IMU signal input and converts them into digital data. The second part handles the GPS data. FPGA-based processing of the GPS signal is carried out to extract data from the required "fields" of the GPS data train. This data is sent to the NPC.

a). Analog Signal Acquisition:

The analog signals from IMU are passed through a second-order Butterworth low-pass filter, and scaled to data acquisition input range and sampled simultaneously, thus preserving the phase information among all the signals in the GIDAC card. There is a delay (¢) between the sampling of each input signal in case a multiplexer is used at the input stage of ADC. Thus, there is a delay of 5¢ by the time the sixth input signal is sampled. Considering ax, ay, az, p, q and r as input channels ch1 to ch6, the position information being considered for calculation from all input signals is not actually correct as it does not belong to the same time instant due to the delays [3—6]. It may be noted that even if all channels are not sampled simultaneously, but the sampling and A/D conversion rate are significantly high, then the effect of errors due to phase delays will be minimal. Non-simultaneous sampling will have impact if computation cycle time is comparable with conversion time. In the present case simultaneous sampling helps in saving valuable DSP time which is otherwise used for controlling the ADC, whereas the correct relative information among all the signals is maintained by simultaneous sampling.

1.1 PS Serial Data Acquisition:

To relieve the main processor from processing overheads during slow speed serial I/O operation, FPGA-based serial port interface is used in the proposed architecture. The FPGA chip is programmed to receive the GPS data from GPS receiver, and generates a busy signal when accessing the in-built dual port RAM (DPRAM). This low-going busy signal interrupts the DSP processor, and the processor fetches the data from the internal DPRAM of the FPGA chip.

1.2 Navigation Processor Card

The INS computations and integration with GPS data are carried out on PIC microcontroller. Control logic signals for selecting peripheral chips are generated using the programmable array logic (PAL). Asynchronous communication is maintained between the GPS module and the NPC card using DPRAM, thus saving the processor time during data transfer.

RESULTS AND DISCUSSION

In order to test the proposed system and to prove that the proposed system performs better than GPS, number of field experiments were carried out.

A vehicle with both GPS system and the INS system was used for this purpose. The vehicle was moved from location A to location B. The path travelled was tracked by both the systems. The resultant images shows that the proposed system is more accurate than that of existing system. The resultant images are give below in that fig 7,9,11 were shown that the GPS tracking position of moving objects fig 8,10,12 are shown that the INS GPS system tracking position of moving objects

As shown in the results the GPS tracking system is not available in particular area. In that area INS is tracking the position of moving vehicle with the use of sensors. We can see in the figure 8. The fig 9 seen GPS sytem showing the position of moving object away from 20 meters so the fig 10 seen INS –GPS System showing the moving the position of object with 3.2 meters.

Figure:7 Path tracked by GPS system

Figure: 8 Path tracked by INS-GPS system

Figure:9 Path(along with divider) tracked by GPS system

Figure:10 Path(along with divider) tracked by INS-GPS system

Figure:11 Path(along with divider) tracked by GPS system

Figure:12 Path(along with divider) tracked by INS GPS system

CONCLUSION

From result analysis, we came to know the integrated INS-GPS architecture produces more accurate result than that of existing system. The manufacturing cost of the proposed system is also less when compared with the existing system. Thus, the integrated INS-GPS system can be used for compact and low power applications.

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