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INTEGRATED NAVIGATION SUBSYSTEM FOR NANO-SATELLITES

ИНТЕГРИРОВАННАЯ НАВИГАЦИОННАЯ ПОДСИСТЕМА ДЛЯ НАНОСПУТНИКОВ

НАНОСПУТНИКТЕРГЕ АРНАЛҒАН ИНТЕГРАЦИЯЛАНҒАН НАВИГАЦИЯЛЫҚ ІШКІ ЖҮЙЕ

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Abstract. The article examines the application of small, low-power satellite navigation receivers in nano-satellites, analyzes the technical performance of unified miniature GPS modules, microelectromechanical (MEMS) inertial measurement modules for nano-satellites and integrated navigation receivers and opportunities have been explored. The integrated navigation subsystem is used to estimate the position, velocity, and attitude of a vehicle with the output of inertial sensors.
Keywords: Integrated Navigation System, Nanosat, CubeSat, MEMS applications, inertial measurement unit (IMU).

Аннотация. В статье исследуется применение малых маломощных спутниковых навигационных приемников в наноспутниках, анализируются технические характеристики унифицированных миниатюрных модулей GPS, микроэлектромеханических (MEMS) модулей инерционных измерений для наноспутников и интегрированных навигационных приемников, а также исследуются возможности. Интегрированная подсистема навигации используется для оценки положения, скорости и ориентации транспортного средства с помощью выходных сигналов инерциальных датчиков.
Ключевые слова: Интегрированная навигационная система, Nanosat, CubeSat, МЭМС-приложения, инерциальный измерительный блок (ИИБ).

Аңдатпа. Мақалада шағын қуатты жерсеріктік навигациялық қабылдағыштардың наноспутниктерде қолданылуы зерттеледі, біріздендірілген шағын GPS модульдерінің, наноспутниктерге және біріктірілген навигациялық қабылдағыштарға арналған микроэлектромеханикалық (MEMS) инерциялық өлшеу модульдерінің техникалық сипаттамалары талданады, сондай-ақ мүмкіндіктері зерттеледі. Интеграцияланған навигациялық Ішкі жүйе инерциялық сенсорлардың шығыс сигналдары арқылы көлік құралының жағдайын, жылдамдығын және бағытын бағалау үшін қолданылады.
Түйін сөздер: интеграцияланған навигациялық жүйе, Nanosat, CubeSat, MEMS қосымшалары, инерциялық өлшеу блогы (ИӨБ).

Introduction. Launched in 1982, the LANDSAT-4 satellite was the first satellite to have a GPS receiver. Several satellites with GPS receivers were launched in the early 1990s, and by 1998, more than 30 satellites were in orbit. In recent years, the use of GPS in small satellites has increased. The availability of small, low-power receivers has led to the use of GPS navigation systems in nano-satellites.

In order to facilitate the participation of science and engineering students in academic satellite development programs, it resulted in the development of 10U10x10cm and a maximum weight of 1 kg in the CubeSat format developed at Stanford University and California Polytechnic State University in 1999.

The advent of small GPS receivers allowed them to be used successfully on small satellites. On the other hand, mass production of MEMS modules in recent years has greatly facilitated the implementation of autonomous navigation equipment even on small satellites. In nano satellites, the integration of satellite navigation and MEMS-based INS (inertial navigation system) equipment improves the accuracy and reliability of navigation data.

Satellite navigation system development began in 1957 with the work of William W. and George C at the Applied Physics Laboratory of Johns Hopkins University [3], resulting in the US Navy Transit GNSS [4]. These programs were instrumental in the concepts and techniques in the development of GPS as well as other satellite-based GNSS that we know today.

- The Global Positioning System (GPS) developed by the United States Department of Defense under NAVSTAR satellite program [5,6];
- Global Orbiting Navigation Satellite System (GLONASS) placed in orbit by the former Soviet Union. In today operated by the Russian Federation [7,8];
- The GALILEO Navigation Satellite System developed by the EU.
- The Bei-Dou NSS (BDS) developed by Republic of China.
- Quasi-Zenith Satellite System (QZSS) developed by the Japanese government.
- The Indian Regional Navigation Satellite Systems (NAVIC) developed by the Indian Space Research Organization.

GNSS/INS integration overview.

As it has playing a vital role in navigation, especially for integrating various navigation modes, The Kalman filter has been named “navigations integration workhorse.” Since it’ s introduction (1960) [10], the Kalman filter has played a significant role in the design and accomplishment of numerous new navigation systems, as an optimal method for computing position using noisy measurements. As it also produces an estimate of its own accuracy, the Kalman filter has also become an important part of a methodology for the optimal designing of many navigation systems. The filter has been very significant for the design and implementation of each GNSS.

The Kalman filter allows navigation system designers to make use of a powerful synergism between INSs and GNSSs, which is feasible because both they have complemental error features:

- Transitory position mistakes from the INS are comparatively small, but they degrade significantly over a period of time.
- Although position accuracies of GNSS are not as good for short period, they don't degrade over time.

The Kalman filter benefits these features to ensure integrated navigation implementation with performance excellent to that of each subsystem (INS or GNSS). The filter uses statistical data about the errors of both systems and allows to combine a system whose position uncertainty which decreases at kilometers per hour (INS) with another system having tens of meters position uncertainty (GNSS). The primary Inertial Measurement Units of INS are accelerometers and gyros, and the navigation information of vehicle is gained by the computation process based on the estimation of IMU. The INS principle is shown in **Figure 1.** [11-13]

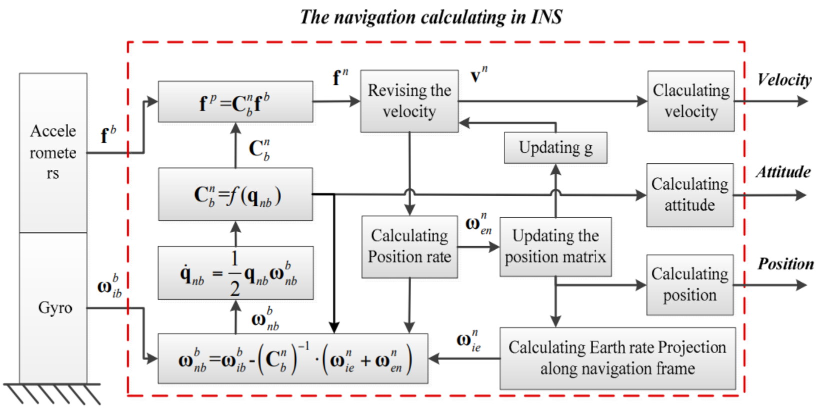

Figure 1. Principle of Inertial Navigation System

Taking into account the MEMS inertial sensors capacity, the mistakes of the sensors due to alignment and temperature are compensated before the angle rate and specific force flow into MEMS-INS. To reject the divergence of the low-precision and the error accumulation MEMS inertial system, the accelerometers outputs are used for interval horizon attitude estimation.

They are also can be used as the measurements to construct the Kalman Filter for detecting the mathematic platform mistakes of MEMS-INS and correcting the attitude of system.

Both INS and GPS were improved for global navigation capability and in common they have shown new levels of high performance which cannot be achieved on its own. The advanced system provides a joint navigation model for both versions of sensors. After that, sensor compensation parameters became the navigation's solution. In short, they are estimated right along with velocity and position, using the inertial sensor outputs and GNSS receiver pseudo ranges. Consequently, whatever occasion GNSS signals are absent, developed accuracy of the sensor compensation parameters outcomes in advanced INS provide alone navigation as long as GNSS signals become available again. The advantageous features of integrated navigation system:

- An INS cannot calculate its longitude and requires minutes to evaluate latitude. GNSS maintains sudden initialization of INS position.
- Due to the integration of GNSS, advancements in INS navigational accuracy ensure better INS-only performance when GNSS signals cannot be reachable.
- Including orientation, velocity, and INS position the INS itself alternates the forward state vector propagation model for the subset of navigation variables.

Inertial Navigation System is a system which estimates the velocity, position, and attitude using various inertial sensors. Because of its limitations in design the measurements of inertial sensors may contain some errors which are accumulated in the navigation process. As a consequence, if the mistake is not recompensed with alternative types of sensors, the data of INS can be used in a short while. Today, the Global Positioning System (GPS) can supply useful data for Inertial Navigation System. Yet, GPS also has several disbenefits, such as signal losing and low sampling rate. The integrated structure of the INS/GPS navigation system is shown in **Figure 2**.

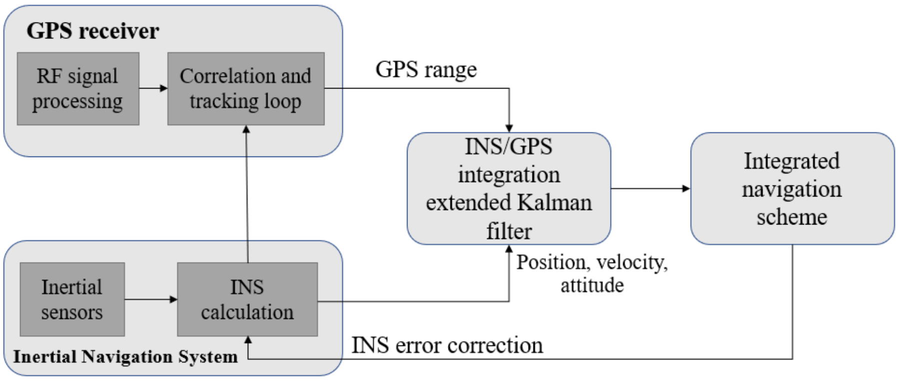

Figure 2. Structure of the INS/GPS integrated navigation system

Hardware & Software.

Study of the modern design principles and performance of the miniature Raspberry Pi 4 Model B mini-computer, NEO-6M GPS module, MPU-6050 sensor allows to create a small integrated navigation system with a wide range of functions.

The Raspberry Pi 4 Model B mini-computer is the fastest option among the existing Raspberry Pi models, with a 4-core processor running at 1.5 GHz and a 2.4 and 5 GHz wireless network chip. With this computer, we can connect, write and manage many digital sensors and interface modules with 40 GPIO lines on it.

GPS Measurements. In recent years, the use of GPS modules offered by u-blox has increased significantly. The GPS Neo-6M can track up to 22 satellites in 50 channels and has the highest sensitivity level among GPS modules while consuming only 45mA of power supply. We can achieve better performance by using 2 GPS antennas.

MEMS IMU Measurements. Accelerometers used in inertial navigation measure the force required to keep a fixed mass constant relative to its enclosure; this is called the special force to distinguish it from undetected gravitational accelerations. Accelerometer designs differ in how this force is measured and how this force is distributed. The turning compass alignment of stationary vehicles uses the local vertical to determine north and the perceived acceleration direction to determine the perceived direction of rotation. Gyrocompass alignment is not required for integrated GNSS / INS navigation, although many INS may already have been configured for this.

MPU-6050 sensors are used in many projects due to their low cost. It is an IMU (Inertial Calculation Unit) sensor board that includes 3-axis gyroscope and 3-axis accelerometer. The card supports the I2C protocol. Since there is a voltage regulator on it, the voltage is between 3v and 5v. The angular velocity measurement range is ± 2 ± 4 ± 8 ± 16 Gauss and the acceleration measurement range is + 250 500 1000 2000 ° / s. **Table 1** shows the summarized of the performance errors of the separate and combined inertial sensors.

Table 1. *INS and sensor performance ranges.*

	Performance ranges			
System or sensor	**High**	**Medium**	**Low**	**Units**
INS	$\leq 10^{-1}$	~1	≥10	NMi/h CEP rate
Gyroscopes	$\leq 10^{-3}$	$\sim 10^{-2}$	$\geq 10^{-1}$	Deg/h drift rate
Accelerometers	$\leq 10^{-7}$	$\sim 10^{-6}$	$\geq 10^{-5}$	g (9.8 m/s^2) bias

Inertial sensors and GPS module are integrated via GPIO pins on Raspberry-pi. Then the appropriate algorithm should be set up. After the algorithm is set up, the codes are programming to the computer (Raspberry) with the Phyton.

Conclusion

The article proposes a structural model of an integrated navigation receiver for CubeSat shaped nano satellites. The hardware of the system based on Raspberry Pi4 is based on low cost and low power MEMS sensors. The integrated circuit has shown that it is possible to more accurately and reliably determine the current position, attitude, velocity of the satellite, as well as include a 3-axis compass sensor in the circuit.

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