2018年 研究生优秀毕业生评定汇总表

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1	ZY1517103	雷朝华	芦佳振	光学工程	########	是	参与学院学术论坛科研经验分享、北航潍坊暑期社会实践、在公益行动、马拉松比赛等做志愿者。	千寻位置网络公司	是	三好学生、“优秀研究生”、研究生国家奖学金、北航优秀学术论文奖、“研究生十佳”、一等学业奖学金、“五四奖章”提名奖。
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SCI（论文类要求（下同）：学生一作、或者学生二作导师一作、或者学生为通讯作者）			EI(期刊)		EI(会议)		专利授权		专利受理	国际会议	核心期刊	其他	个人陈述	备注
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Improved calibration of IMU biases in analytic coarse alignment for AHRS

Jiazhen Lu, Chaohua Lei, Baoguo Li and Ting Wen

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Abstract

An improved method for the inertial measurement unit (IMU) calibration of coarse alignment for the low-accuracy attitude heading reference system (AHRS) is proposed in this paper. The sensitivities of the Euler angles with respect to the inertial sensor biases are studied based on the analytic coarse alignment principle, and the errors of earth rotation rate and local gravity in the body frame caused by initial attitude error are analyzed. Then, an improved analytic coarse alignment algorithm with accelerometer and gyro bias calibration in an arbitrary three-position is proposed. Simulation and experiment results show that the novel method can calibrate accelerometer and gyro biases, reduce Euler angle attitude error, and improve navigation precision in practical applications. Moreover, this method can be applied to other low-accuracy inertial navigation systems.

Keywords: AHRS, calibration, coarse alignment, IMU biases, inertial sensor

(Some figures may appear in colour only in the online journal)

Nomenclature

i	Inertial frame
e	Earth frame
b	Body frame
n	Navigation frame
C_b^n	Initial body attitude matrix with respect to the navigation frame
g	Local gravity
ω_{ie}	Earth rotational rate
ω_{ie}^b	Earth rotational rate in the body frame
ω_{ie}^n	Earth rotational rate in the navigation frame
f^b	Accelerometer output
ω_{ib}^b	Gyro output
a	Accelerometer bias
ε	Gyroscope bias
λ	Longitude
ϕ	Latitude
θ	Pitch
γ	Roll
φ	Azimuth

1. Introduction

The attitude heading reference system (AHRS) is an integrated navigation system, which usually consists of a low-accuracy strap-down inertial navigation system (SINS), global positioning system (GPS), and the magnetometer. The AHRS can provide information such as horizontal attitudes and heading. The performance of AHRS chiefly depends on the navigation accuracy of the SINS [1]. The SINS has some special advantages, such as strong autonomy, and provides continuous and comprehensive information including position, speed, and attitude. In addition, it has been widely applied in military and civil fields, such as to types of civil aircraft, vehicle navigation [2], surveying and mapping in the civil field, and types of military aircraft, missiles navigation, warships and its weapons systems in the military field [3]. However, the navigation errors of the SINS diverge with time mainly due to the existence of biases in inertial sensors, which includes three accelerometers and three gyros, and initial attitude errors [4]. Thus the calibration and compensation of biases in accelerometers and gyros in the initial alignment process is an effective way to reduce initial attitude error and improve the navigation accuracy of SINS [5].

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A high-accuracy two-position alignment inertial navigation system for lunar rovers aided by a star sensor with a calibration and positioning function

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Abstract

An integrated inertial/celestial navigation system (INS/CNS) has wide applicability in lunar rovers as it provides accurate and autonomous navigational information. Initialization is particularly vital for a INS. This paper proposes a two-position initialization method based on a standard Kalman filter. The difference between the computed star vector and the measured star vector is measured. With the aid of a star sensor and the two positions, the attitudinal and positional errors can be greatly reduced, and the biases of three gyros and accelerometers can also be estimated. The semi-physical simulation results show that the positional and attitudinal errors converge within 0.07″ and 0.1 m, respectively, when the given initial positional error is 1 km and the attitudinal error is 10°. These good results show that the proposed method can accomplish alignment, positioning and calibration functions simultaneously. Thus the proposed two-position initialization method has the potential for application in lunar rover navigation.

Keywords: INS/CNS, IMU calibration, two-position alignment, positioning, initialization

(Some figures may appear in colour only in the online journal)

1. Introduction

Lunar rovers play an important role in the task of lunar exploration. They can take the place of humans in gathering surface information and sampling lunar materials for scientific study. Precise real-time position and velocity information, which is obtained by navigation, is necessary to complete tasks. Lunar rovers are generally controlled and monitored by a ground control center. However, there are delays, and thus poor real-time information, due to the long distances involved and signal jamming [1, 2]. The accuracy of positional information is about 1 km. Thus for autonomous and continuous navigation it is essential to provide positional and velocity information when ground control is not optimal.

Inertial navigation systems (INS) have been widely applied in military and civil fields. INS have strong real-time autonomy, are immune to environmental effects and provide continuous and comprehensive information in a short time [3]. Navigational errors will accumulate with time as a result of many error sources, include initialization, inertial sensor bias and computation, and a complementary navigational device is usually needed to help mitigate errors in a INS [4]. External aids which provide extra information are usually integrated with a INS. A global positioning system (GPS) is a popular choice for integration with a INS using a Kalman filter (KF) [5]. However, GPS is unavailable in hostile environments and signal outage can occur. Furthermore, GPS is an Earth-based application.

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In-motion initial alignment and positioning with INS/CNS/ODO integrated navigation system for lunar rovers

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Abstract

Many countries have been paying great attention to space exploration, especially about the Moon and the Mars. Autonomous and high-accuracy navigation systems are needed for probers and rovers to accomplish missions. Inertial navigation system (INS)/celestial navigation system (CNS) based navigation system has been used widely on the lunar rovers. Initialization is a particularly important step for navigation. This paper presents an in-motion alignment and positioning method for lunar rovers by INS/CNS/odometer integrated navigation. The method can estimate not only the position and attitude errors, but also the biases of the accelerometers and gyros using the standard Kalman filter. The differences between the platform star azimuth, elevation angles and the computed star azimuth, elevation angles, and the difference between the velocity measured by odometer and the velocity measured by inertial sensors are taken as measurements. The semi-physical experiments are implemented to demonstrate that the position error can reduce to 10 m and attitude error is within 2″ during 5 min. The experiment results prove that it is an effective and attractive initialization approach for lunar rovers.

Keywords: Celestial navigation system; Inertial navigation system; Initial alignment and positioning; Standard Kalman filter

1. Introduction

Many countries have been focusing on the space exploration to grope after the mystery of the universe. Recent years, the Moon and the Mars are the prime exploration targets (Ning et al., 2009). China's Lunar Exploration Project has three stages, including exploration around the Moon, landing on the Moon and returning an Unmanned Aerial Vehicle with samplings. After the success of lunching the Chang'e series and the YuTu Rover, China has accomplished two phases. In the landing missions, the lunar rovers play a particularly crucial role to explore the surface of Moon. The ground controlling center needs to know the real-time position information of the rovers precisely. To compensate the limitation that the information from ground tracking is not continuous and has delay or jamming, the inertial navigation system (INS)/celestial navigation system (CNS) integrated navigation has been widely used on the rovers (Zhu et al., 2014). INS is an autonomous and continuous navigation means (Strachan, 2000), whose calculation is an integration process. Thus, the navigation error will accumulate with time due to the drifts of the accelerometers and gyros. As a result, INS navigation system needs real-time compensation to improve the accuracy. CNS navigation (Guanghua, 1991) is also autonomous and has a good performance irrelevant to time and distance. Thus, INS/CNS integrated navigation is an ideal combination to provide the accurate position information for Lunar rover in real time (Khan et al., 2015).

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Applied system-level method in calibration validation for personal navigation system in field

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Abstract: A system-level method to validate previous calibration results for low-precision inertial measurement unit (IMU) in personal navigation system (PNS) is proposed. Micro-electro mechanical systems inertial sensors have gained popularity in PNS because they are small, compact and inexpensive. However, the calibration results of these sensors which belong to low-grade IMU will change as time and environment change. It is significant to know whether previous calibration results are reliable for navigation after a long time. However, users have no devices such as turntable to validate calibration results precisely. Therefore, a triple two-position method without any external aiding is presented to validate the bias errors relative to previous calibration results. If the errors are less than the bias range which is a priori information calculated in previous lab test, previous calibration results are available, otherwise the calibration results is invalid. The two-position method based on the strong tracking filter, which takes velocity and azimuth errors as observations, can estimate the bias and scale factor errors of accelerometers and gyros. The experimental results show that the proposed method is effective, compared with the conventional 24-position calibration method on the turntable and the system-level multi-position method usually used for high-grade IMU.

1 Introduction

The personal navigation system (PNS) recently has been extensively used in people's lives [1]. It is particularly important for disabled and soldier in duty when they are lost somewhere and cannot contact with outside. Furthermore, consumers use a PNS in their vehicle to offer driving information.

Based on global positioning system (GPS) navigation which can provide accurate position and velocity information is a primary system currently. However GPS has its limits that is unavailable in some challenge environments. During the GPS signal outages, inertial measurement unit (IMU) which is autonomous and can provide continuous navigation information in despite of outside environments is a good solution to this problem [2, 3]. Micro-electro mechanical systems (MEMS) inertial sensors have many advantages in size, weight, cost and power consumption. Therefore, they have been the optimal choice for PNS. Recently, low-cost PNS based on MEMS IMU have become a focus in the navigation field [4, 5].

MEMS IMU is usually composed of three accelerometers and three gyros, and they need to be calibrated in lab to remove the major part of the deterministic sensor errors before they can be used. MEMS IMU is a sort of low-precision sensor, the calibration results of which may have a large bias error of after a long time compared with previous results in lab [6]. However, consumers might directly mount a PNS on foot or in their vehicle without checking the calibration results whether they have large errors. Meanwhile they have no devices to calibrate IMU precisely. Thus, a simple and practical method to checkout previous calibration results is required.

A large amount of papers have been published about MEMS calibration method in recent years. For normal calibration method in lab, Aggarwal presented a standard testing and calibration procedure for low cost MEMS IMU [7]. The six-position static method and rate tests separately estimate the deterministic sensor errors including bias, scale factor, and non-orthogonalities of accelerometer and gyros. Syed and Tuukka, respectively, proposed a multi-position and an enhanced multi-position calibration method for MEMS inertial navigation systems, which do not require special alignment but also a turntable [8, 9]. However for MEMS grade sensors, the bias and scale factor will change due to the dependence of environment and time, the large errors of which will produce the large navigation error. There has been a long time from last lab calibration of MEMS IMU when consumers use a PNS. It is necessary to know whether the calibration results are correct and available. Thus, Fong and Li, respectively, proposed a multi-position method and an improved hand multi-position method through multiple quasi-static states generated by hand holding for in-field user calibration of MEMS IMU without external equipment [10, 11], but the bias range referring to different bias errors in different directions of accelerometers and gyros in this paper is not taken into account. Aggarwal studied a heuristic elimination of gyro drift for PNSs in GPS-denied conditions, but other errors except gyro drift are not considered [12]. Vinande presented several methods of mounting-angle estimation for personal navigation devices [13], whereas there is no mention about bias and scale factor error. For high-precision IMU, the system-level multi-position method in-field can estimate the error parameters [14]. It is unsuitable for low-precision MEMS IMU, because the Kalman filter will be unstable due to the bias range. The experiment section of the paper has proved the fact by simulation and test. Besides, it is impossible to validate calibration results using turntable in lab, although it is precise.

Therefore, a fast triple two-position method to validate calibration parameter using system-level method is proposed in this paper. The primary large errors including bias and scale factor errors of accelerometers and gyros can be estimated. If the errors are in a certain range, previous calibration results can be used continually. Otherwise, sensors need to be calibrated once more in lab or IMU is no longer considered valid. The strong tracking filter (STF) can be used to estimate the time-varying parameters with unknown changing law. Qian applied the STF to the initial alignment for rotational strap-down inertial navigation system [15]. Because of bias range, the bias error will change in two positions. Thus the proposed method uses the STF to estimate the changing bias errors. The proposed method without requiring turntable is fast,

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A Dynamic Precision Evaluation Method for the Star Sensor in the Stellar-Inertial Navigation System

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Jiazhen Lu, Chaohua Lei & Yanqiang Yang

Integrating the advantages of INS (inertial navigation system) and the star sensor, the stellar-inertial navigation system has been used for a wide variety of applications. The star sensor is a high-precision attitude measurement instrument; therefore, determining how to validate its accuracy is critical in guaranteeing its practical precision. The dynamic precision evaluation of the star sensor is more difficult than a static precision evaluation because of dynamic reference values and other impacts. This paper proposes a dynamic precision verification method of star sensor with the aid of inertial navigation device to realize real-time attitude accuracy measurement. Based on the gold-standard reference generated by the star simulator, the altitude and azimuth angle errors of the star sensor are calculated for evaluation criteria. With the goal of diminishing the impacts of factors such as the sensors' drift and devices, the innovative aspect of this method is to employ static accuracy for comparison. If the dynamic results are as good as the static results, which have accuracy comparable to the single star sensor's precision, the practical precision of the star sensor is sufficiently high to meet the requirements of the system specification. The experiments demonstrate the feasibility and effectiveness of the proposed method.

The inertial navigation system (INS), which can provide continuous and comprehensive navigation information of a carrier by using a gyro and an accelerometer, has been widely applied in military and civilian fields[1–3]. However, navigation errors accumulate over time in this system as a result of many error sources, such as initialization error, inertial sensor bias and computational error. Therefore, other navigation approaches are necessary to mitigate these errors in INS[4–8]. With the development of optoelectronics and image-processing techniques, the star sensor based on a charge-coupled device (CCD) or complementary metal-oxide semiconductor (CMOS) has become an attitude measurement instrument with the highest accuracy[9–11]. The star sensor offers many good characteristics: it is non-radiating, invulnerable to jamming and invariant to changes in time and distance, and it can obtain high-precision attitude information of a body in an inertial frame[12, 13]. Therefore, the stellar-inertial navigation system combines INS and the star sensor to take advantage of both their merits; indeed, the stellar-inertial navigation system is a promising combination for application to marine systems, military aircraft and deep-space exploration[14–18]. Because the accuracy of the star sensor, which can reach the arc-second level, directly determines the integrated navigation accuracy, verification of star sensor accuracy becomes an important step in stellar-inertial integration applications.

Many researchers have studied calibration and accuracy verification methods for the single star sensor[19–23]. The standard procedure is that the accuracy of the star sensor is tested after the application of various calibration methods; in other words, the verification experiment aims to verify the presented calibration method and then demonstrates the accuracy of the star sensor. Various calibration algorithms, both ground-based and on-orbit, have been proposed to estimate the most effective values of the optical parameters of the star camera using least-squares estimation or another fitting method[24–27]. Then, laboratory simulations or real night-sky tests are implemented to evaluate the accuracy of the star sensor after parameter compensation and to further assess the performance of the calibration methods. Thomas developed a complete calibration and qualification process for the TERMA star tracker to test its performance[28]. In addition, with the advanced development of the high-precision star simulator, the in-lab calibration accuracy of the single star sensor has improved dramatically[29, 30]. Regarding the accuracy evaluation method of the star sensor, Sun proposed an accuracy measurement method

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An All-Parameter System-Level Calibration for Stellar-Inertial Navigation System on Ground

Jiazhen Lu, Chaohua Lei, Shufang Liang, and Yanqiang Yang

***Abstract*— The calibration, in particular about the installation errors of a star sensor, is a vital problem when improving the accuracy of stellar-inertial navigation system (INS). This paper proposed an all-parameter calibration method for a ground-based stellar-INS with 12-position rotations, using a Kalman filter that can simultaneously estimate bias, scale factor, misalignments of inertial measurement unit (IMU), and installation errors of star sensor. The difference between the star vector measured by the star sensor and the gold reference generated by the star simulator is used as an observation. On the basis of observability to all parameters, the accuracy is greatly enhanced through an iterative method. Better than previous separate calibration of INS and star sensor, the proposed method offers an advantage in that installation error is slightly influenced by IMU drift and device precision. The experimental results demonstrate that all estimated parameters have good stability and repeatability, with the maximum attitude error of integrated navigation less than 6″ after compensation, compared with 20″ using the traditional method. It is shown that the proposed calibration method can efficiently improve the navigation performance of stellar-INS, which has been extensively used in shipborne systems, military aircraft, and missile systems.**

***Index Terms*— 12-position rotations, all-parameter calibration, installation errors of star sensor, linear Kalman filter, star sensor, stellar-inertial navigation system (INS).**

I. Introduction

An INERTIAL navigation system (INS), which can provide navigation information including velocity, position, and attitude continuously, has been a research focus in navigation field. Although the INS offers numerous advantages, including strong autonomy and being completely self-controlled, its navigation information degrades with time due to sensor errors [1]. Thus, integrating the INS with other navigation means is a commonly used method to overcome inertial divergence over time [2]. The star sensor is a high-precision attitude measurement device utilizing a light detector to gather the lines of sight from two or more stars in space yielding accurate attitude information for a body in the inertial frame [3], [4]. The advantages of a star sensor are that it is nonradiating, invulnerable to jamming and has no drift with time. However, it has a low output update rate and cannot offer the position and velocity information of body. Therefore, the stellar-INS based on the INS and star sensor, integrating both advantages, has been used for a wide variety of applications including marine system, military aircraft, and Moon's rovers [5], [6].

Calibration is necessary for a navigation system to be used for compensating sensor errors. Traditionally, an inertial measurement unit (IMU) needs to calibrate bias, scale factor, and misalignments of three gyros and accelerometers [7]. The conventional calibration method is to observe the outputs of accelerometers and gyros compared with the known gravity force and rotational velocity. For the stellar-INS, the calibration of installation error of the star sensor is also pivotal because the accuracy of star sensor can reach arc-seconds. If the installation error reaches several arc-minutes, then the precision of star sensor greatly degrades. Numerous works have been studied calibration method of stellar-INS. However, the calibration of IMU and star sensor are introduced separately. Typical calibration methods of INS involve static multiposition rotation test using a high-precision turntable with analytic methods [8], [9]. In addition, many researchers study the system-level calibration method, whose principle is using the outputs of gyro and accelerometer under designed rotation sequences to compute navigation results, then comparing them with a navigation information reference, such as zero velocity, to deduce the sensor parameters by filter or fitting methods. An eight-position self-calibration method for a dual-axis rotational INS is provided to calibrate constant bias, scale factor, misalignment, and g-dependent bias [10]. A novel integrated calibration method by a hybrid analytic/extended Kalman filter approach is proposed in [11], in which the 4 rotations and 11 positions are separately designed for analytic calibration and fine calibration. System-level calibration method is preferable for a more convenient, comprehensive, and economical performance, facilitating a rapid and on location response.

There are also numerous literature works to propose calibration methods of installation errors between a star sensor and an INS. A traditional method is that a two-position overturning calibration method with a single star simulator is carried out on the marble flat, and the accelerometer's output and star simulator information are used as a reference [12]. Nevertheless, the precondition is that the inertial sensor is calibrated accurately and the drift both in run and from switch-ON to switch-ON of IMU is neglected. The other method is the on-orbit calibration approach based on navigation solution to obtain star sensor installation errors. Using the difference of

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