Contents lists available at SciVerse ScienceDirect

# ELSEVIER



Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

## An autonomous navigation scheme based on geomagnetic and starlight for small satellites

### Wang Xinlong<sup>a</sup>, Wang Bin<sup>a,\*</sup>, Li Hengnian<sup>b</sup>

<sup>a</sup> School of Astronautics, Beihang University, Beijing 100191, China
<sup>b</sup> State Key Lab of Astronautical Dynamics, Xi'an Satellite Control Center, Xi'an 710043, China

#### ARTICLE INFO

Article history: Received 19 April 2012 Received in revised form 9 July 2012 Accepted 15 July 2012 Available online 21 August 2012

Keywords: Small satellites Autonomous navigation Star sensors Geomagnetic field UKF

#### ABSTRACT

According to the characteristics of celestial navigation system (CNS) and geomagnetic navigation system (GNS), a fully autonomous geomagnetic/celestial integrated navigation scheme (GNS/CNS) is proposed for small satellites. By using a large-view-field star sensor to obtain the starlight vectors of multi-stars, CNS can make up the shortcoming of navigation accuracy of GNS. The system model of GNS/CNS is deduced and established in detail, and UKF (unscented Kalman filter) algorithm is used to estimate and obtain high precision navigation parameters. Simulation results show that superior position, velocity and attitude accuracy of small satellites can be obtained by GNS/CNS, and the filter has stronger filtering adaptability and stability, which demonstrate the feasibility and effectiveness of this scheme.

© 2012 Elsevier Ltd. All rights reserved.

#### 1. Introduction

Small satellites have various characteristics, such as light weight, low cost, short manufacturing period, etc. Small satellite networks will play more and more important roles in the fields of communication, remote sensing, and navigation [1–2]. With the increasing number of low/ medium orbit small satellites, traditional ground-based tracking scheme can hardly meet the measurement requirements of small satellite networks.

Satellite autonomous navigation is determining navigation parameters of satellites without the help of groundbased tracking and fulfills the mission only using onboard measurement information [3]. The traditional groundbased navigation method is rather accurate and has been successfully applied to navigate the spacecrafts, but it has high mission costs. For numerous low/medium earth orbit

\* Corresponding author. Tel.: +86 10 82339795.

E-mail address: wangbinbuaa@126.com (W. Bin).

0094-5765/ $\$  - see front matter  $\$  2012 Elsevier Ltd. All rights reserved. http://dx.doi.org/10.1016/j.actaastro.2012.07.013 spacecrafts, the domestic networks of ground stations cannot give enough capacity to control these spacecrafts. While in deep space environment, the ground stations are powerless to establish the communication, and the missions may be failed. Autonomous navigation can not only improve the safety and viability of spacecrafts, but also greatly reduce the costs of the ground measurement system [4–6]. Consequently, how to realize autonomous navigation has become a crucial problem in designing small satellite systems.

In recent years, some of satellite navigation methods have been proposed and explored, including inertial navigation system (INS) [7], Global Position System (GPS) [8–9], inter-satellite link [10–11], geomagnetic navigation (GNS) [12–16] and celestial navigation (CNS) [17–20]. INS is an available navigation method, but its navigation error accumulates with time extension. To improve the navigation performance and prevent the increase of errors, INS is usually integrated with GPS or other navigation sensors [21–23]. GPS and inter-satellite link can provide real-time navigation information with high accuracy, but they are only semi-autonomous methods, because they must depend

SNR

FOV

A<sub>cir</sub>

Signal to Noise Ratio

The wide of a circular FOV (deg.)

Field of View

ivonichciacaic
----------------

Symbols

$\begin{array}{llllll} 0, X_i,Y_i Z_i \\ \text{Inertial coordinate system} \\ Q_e X_e Y_e Z_e \\ \text{Exth-fixed coordinate system} \\ Q_e X_e Y_e Z_e \\ \text{Exth-fixed coordinate system} \\ Q_e X_i Y_e Z_e \\ \text{Geographic coordinate system} \\ Q_e X_i Y_e Z_i \\ \text{Geographic coordinate system} \\ Q_e X_i Y_e Z_i \\ \text{Geographic coordinate system} \\ O_p X_p Y_p \\ \text{Imaging plane coordinate system} \\ ONET \\ \text{Local geographic (north, east, and nadir) coordinate system to inertial coordinate system for inate system to inertial coordinate system \\ C_i^h \\ \text{Transformation matrix from inertial coordinate system} \\ C_i^h \\ \text{Transformation matrix from inertial coordinate system} \\ C_i^h \\ \text{Transformation matrix from inertial coordinate system} \\ X,Y.Z \\ \text{East, north, and down component of geomagnetic field vector (nT) \\ P_m^m \\ \text{Legendre functions of degree n and order m in Schmidt quasi-normalized form \\ B_r, B_{\theta}, B_i \\ \text{The geomagnetic field vector in geographic coordinate system} \\ \Delta B \\ \text{The error between the measurement and estimate geomagnetic field vector (nT) \\ P_m \\ \text{The measurement geomagnetic field vector from \\ F \\ \text{The total intensity of geomagnetic field vector in angle (deg.) \\ I \\ \text{The inclination angle (deg.) \\ I \\ \text{The inclination angle (deg.) \\ I \\ \text{The starlight vector in satellite body coordinate system \\ L_m \\ \text{The starlight vector in satellite body coordinate system \\ I_m \\ M_V \\ = \text{The magnitude of star \\ \end{array} $			N <sub>FOV</sub>	Average number of stars in a FOV
$\begin{array}{llllllllllllllllllllllllllllllllllll$	$O_i X_i Y_i Z_i$	Inertial coordinate system	liim	The measurement light intensity for each
$\begin{array}{llllllllllllllllllllllllllllllllllll$	$O_e X_e Y_e Z_e$	e Earth-fixed coordinate system	. <u>.</u> ,,,,,	pixel of the star image
$Q_x X_y Z_s$ The star sensor coordinate system $Q_p X_p Y_p$ Imaging plane coordinate system Local geographic (north, east, and nadir) coordinate system dinate system to inertial coordinate system $C_n^1$ Transformation matrix from geographic coordinate system tic field vector (nT) $\partial R_s \partial V$ Satellite position and velocity relative to orbit coordinate system (rad/s) $R_s U_s Z_s$ mate system to body coordinate system tic field vector (nT) $\partial R_s U_s Z_s$ $R_s U_s Z_s The field vector components in geomagneticspherical coordinate systemcoordinate system\partial R_s U_s Z_sZ_s Z_s U_s U_s U_s U_s U_s U_s U_s U_s U_s U$	$X_n Y_n Z_n$	Geographic coordinate system	RV	The position and velocity in initial coordinate
$\begin{array}{llllllllllllllllllllllllllllllllllll$	$O_s X_s Y_s Z_s$	The star sensor coordinate system	10,7	system
ONETLocal geographic (north, east, and nadir) coordinate systemSatellite angular velocity relative to orbital angular velocity relative to orbital angular velocity relative to inertial coordinate system $C_n^i$ Transformation matrix from geographic coordinate system to body coordinate system $\overline{w}_{ab}$ Satellite angular velocity relative to inertial coordinate system (rad/s) $C_n^i$ Transformation matrix from inertial coordinate system to body coordinate system $\overline{w}_{ab}$ Satellite angular velocity relative to inertial coordinate system (rad/s) $X,Y,Z$ East, north, and down component of geomagnetic field vector (nT) $\overline{w}$ Satellite angular velocity relative to inertial space (rad/s) $P_m^m$ Legendre functions of degree n and order m in Schmidt quasi-normalized form $\overline{w}$ Satellite angular velocity relative to inertial space (rad/s) $B_r, B_0, B_{\hat{z}}$ The field vector in geographic coordinate system $\overline{w}$ Satellite angular velocity relative to inertial space (rad/s) $B_r, B_0, B_{\hat{z}}$ The field vector in geographic coordinate system $\overline{w}$ Satellite angular velocity relative to inertial space (rad/s) $B_r, B_0, B_{\hat{z}}$ The field vector in geographic coordinate system $\overline{Q}_0^i$ Attitude matrix expressed by quaternion $\overline{\Delta q}$ $B_r, B_0, B_{\hat{z}}$ The field vector in geographic coordinate system $\overline{D}_2^i$ The vector part of attitude error quaternion $\overline{\Delta q}$ $B_r, B_0, B_{\hat{z}}$ The measurement geomagnetic field vector $\overline{P}_0^i$ The geomagnetic field vector in geographic coordinate system $B_r$ The error between the measurement angle (deg.) $\overline{P}_1^i$ The magnetom	$O_p X_p Y_p$	Imaging plane coordinate system	$\delta R  \delta V$	Satellite position and velocity errors in iner-
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	ONET .	Local geographic (north, east, and nadir) coor-	011,01	tial coordinate system
$\begin{array}{cccc} c_n & \mbox{Transformation matrix from geographic coordinate system to inertial coordinate system (rad/s) \\ coordinate system to body coordinate system \\ X,Y,Z & East, north, and down component of geomagnetic field vector (nT) \\ p_n^m & Legendre functions of degree n and order m in schmidt quasi-normalized form \\ B_r,B_{\theta},B_{z} & The field vector components in geomagnetic field vector in geographic coordinate system \\ \Delta B & The geomagnetic field vector \\ F & The total intensity of geomagnetic field vector \\ F & The total intensity of geomagnetic field vector (nT) \\ D & The declination angle (deg.) \\ I & The inclination angle (deg.) \\I & The starlight vector in starlight vector and system \\ L_m & The starlight vector in satellite body coordinate system \\ L_m & The starlight vector in satellite body coordinate system \\ M_V & = The magnitude of star \\ \end{array}$		dinate system	147	Satellite angular velocity relative to orbit
ndinate system to inertial coordinate system $\overline{W}_{10}$ Orbital angular velocity relative to inertial coordinate system (rad/s) $C_1^b$ Transformation matrix from inertial coordi- nate system to body coordinate system $\overline{W}_{10}$ Orbital angular velocity relative to inertial coordinate system (rad/s) $X,Y,Z$ East, north, and down component of geomag- netic field vector (nT) $\overline{W}$ Satellite angular velocity relative to inertial space (rad/s) $P_n^m$ Legendre functions of degree n and order m in Schmidt quasi-normalized form $\overline{W}$ Satellite angular velocity error relative to inertial space (rad/s) $B_r,B_0,B_2$ The field vector components in geomagnetic spherical coordinates (nT) $\Delta \overline{W}$ Satellite angular velocity error relative to inertial space (rad/s) $B$ The geomagnetic field vector in spherical coordinates (nT) $\Delta \overline{Q}$ The attitude quaternion $\Delta \overline{Q}$ $AB$ The error between the measurement and estimate geomagnetic field vector $D$ The declination angle (deg.) $F$ The total intensity of geomagnetic field vector (nT) $D$ The declination angle (deg.) $U$ $D$ The angle between starlight vector and mea- surement geomagnetic field vector (deg.) $U$ $D$ $U$ The starlight vector in star sensor coordinate system $C$ $C$ $M_m$ The starlight vector in satellite body coordi- nate system $T$ $E$ $f$ = Focal length (mm) $J$ $J$ $M_V$ = The magnitude of star $J$ $J$	$C_n^i$	Transformation matrix from geographic coor-	vv ob	coordinate system (rad/s)
$C_i^b$ Transformation matrix from inertial coordinate system $W_{io}$ Orbital angular velocity relative to inertial coordinate system (rad/s) $X,Y,Z$ East, north, and down component of geomagnetic field vector (nT) $\overline{W}$ Satellite angular velocity relative to inertial space (rad/s) $m_n^m$ Legendre functions of degree n and order m in Schmidt quasi-normalized form $\overline{W}$ Satellite angular velocity error relative to inertial space (rad/s) $B_r, B_{\theta}, B_{\lambda}$ The field vector components in geomagnetic spherical coordinate system $\overline{Aw}$ Satellite angular velocity error relative to inertial space (rad/s) $B$ The geomagnetic field vector in geographic coordinate system $\overline{C}_{b}^{b}(q)$ Attitude matrix expressed by quaternion $\Delta B$ The error between the measurement and estimate geomagnetic field vector $\overline{L}_{\mu}$ The second zonal coefficient $B_m$ The measurement geomagnetic field vector $v_L$ The measurement noise of the star sensor (" $F$ The total intensity of geomagnetic field vector (dg.) $v_{B1}$ The magnetometer measurement noise (mT) $D$ The declination angle (deg.) $v_{B1}$ The magnetometer measurement noise (dg.) $I$ The inclination angle (deg.) $v_{B1}$ Superscripts and subscripts $I$ The starlight vector in star sensor coordinate system $v_{A1}$ $I_m$ The starlight vector in star sensor coordinate system $v_{A1}$ $I_m$ The starlight vector in star sensor coordinate system $v_{A1}$ $I_m$ The starlight vector in star sensor coordinate system $v_{A1}$ $I_m$	"	dinate system to inertial coordinate system		Orbital angular velocity relative to inertial
$\begin{array}{llllllllllllllllllllllllllllllllllll$	$C_{i}^{b}$	Transformation matrix from inertial coordi-	W <sub>io</sub>	oldital aliguial velocity felative to inertial
X,Y,ZEast, north, and down component of geomagnetic field vector (nT)WSatellite angular velocity relative to inertial space (rad/s) $P_n^m$ Legendre functions of degree n and order m in Schmidt quasi-normalized formSatellite angular velocity error relative to inertial space (rad/s) $B_r,B_{\theta},B_{z}$ The field vector components in geomagnetic spherical coordinates (nT)The vector part of attitude error quaternion $B$ The geomagnetic field vector in geographic coordinate system $\Delta \overline{Q}$ The vector part of attitude error quaternion $\Delta B$ The error between the measurement and estimate geomagnetic field vector $\Delta \overline{Q}$ The second zonal coefficient $B_m$ The measurement geomagnetic field vector $V_L$ The measurement noise of the star sensor (" $B_m$ The enclination angle (deg.) $V_L$ The magnetometer measurement noise (nT) $D$ The declination angle (deg.) $V_R$ Superscripts and subscripts $I$ The inclination angle (deg.) $V_R$ Superscripts and subscripts $I_m$ The starlight vector in star sensor coordinate system $V_R$ Estimate value $I$ $V_R$ The anglitude of star $V_R$	-1	nate system to body coordinate system		Coolullate system (Idd/S)
$\begin{array}{llllllllllllllllllllllllllllllllllll$	X Y 7	Fast north and down component of geomag-	W	Satellite angular velocity relative to mertial
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	11,1,2	netic field vector (nT)	<u>،                                     </u>	space (rad/s)
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\mathbf{P}^m$	Legendre functions of degree <i>n</i> and order <i>m</i> in	$\Delta W$	Satellite angular velocity error relative to
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	<sup>1</sup> n	Schmidt quasi-normalized form		inertial space (rad/s)
$\begin{array}{cccc} D_{P}B_{0}, B_{2} & \text{The neuron components in geomagnetic results of coordinates (nT)} \\ B & \text{The geomagnetic field vector in geographic} \\ coordinate system \\ \Delta B & \text{The error between the measurement and} \\ estimate geomagnetic field vector \\ B_{m} & \text{The measurement geomagnetic field vector} \\ F & \text{The total intensity of geomagnetic field} \\ vector (nT) \\ D & \text{The declination angle (deg.)} \\ I & \text{The inclination angle (deg.)} \\ I & \text{The starlight vector in star sensor coordinate} \\ system \\ L_{m} & \text{The starlight vector in satellite body coordinate system} \\ f & = \text{Focal length (mm)} \\ M_{V} & = \text{The magnitude of star} \\ \end{array}$	R R. R.	The field vector components in geomagnetic	$q_{p}$	The attitude quaternion
$\begin{array}{rcl} \Delta \overline{g} & \text{The vector part of attitude error quaternion} \\ \overline{g} & \text{The geomagnetic field vector in geographic} \\ coordinate system & \\ \Delta B & \text{The error between the measurement and} \\ estimate geomagnetic field vector & \\ B_m & \text{The measurement geomagnetic field vector} \\ F & \text{The total intensity of geomagnetic field} \\ vector (nT) & \\ D & \text{The declination angle (deg.)} \\ I & \text{The inclination angle (deg.)} \\ J & \text{The angle between starlight vector and measurement geomagnetic field vector} \\ w & \\ M_m & \text{The starlight vector in star sensor coordinate} \\ system & \\ L_m & \text{The starlight vector in satellite body coordinate system} \\ f & = \text{Focal length (mm)} \\ M_V & = \text{The magnitude of star} \\ \end{array}$	$D_r, D_\theta, D_\lambda$	spherical coordinates (nT)	$C_o^{\nu}(q)$	Attitude matrix expressed by quaternion
$\begin{array}{llllllllllllllllllllllllllllllllllll$	D	The geomegnetic field vector in geographic	$\Delta \overline{q}$	The vector part of attitude error quaternion
$\Delta B \qquad \text{The error between the measurement and} \\ estimate geomagnetic field vector \\ B_m \qquad \text{The measurement geomagnetic field vector} \\ F \qquad \text{The total intensity of geomagnetic field vector} \\ F \qquad \text{The total intensity of geomagnetic field vector} \\ I \qquad \text{The inclination angle (deg.)} \\ I \qquad \text{The angle between starlight vector and measurement geomagnetic field vector (deg.)} \\ U \qquad \text{The starlight vector in star sensor coordinate} \\ system \\ L_m \qquad \text{The starlight vector in satellite body coordinate system} \\ f \qquad = \text{Focal length (mm)} \\ M_V \qquad = \text{The magnitude of star} \\ \end{bmatrix} \begin{array}{c} J_2 \qquad \text{The second zonal coefficient} \\ P(J_2) \qquad \text{Perturbation acceleration caused by } J_2 (m/s^2) \\ W_L \qquad \text{The measurement noise of the star sensor ("} \\ W_{B1} \qquad \text{The magnetometer measurement noise (nT)} \\ \psi_{B1} \qquad \text{The magnetometer measurement noise (nT)} \\ \psi_{B2} \qquad \text{Geomagnetic field model noise (nT)} \\ \psi_{B2} \qquad \text{Geomagnetic field model noise (nT)} \\ \psi_{\beta} \qquad \text{Angle measurement noise (deg.)} \\ & Superscripts and subscripts \\ & \text{Value in inertial coordinate system} \\ & \text{Value in satellite body coordinate system} \\ & \text{Value in satellite body coordinate system} \\ & \text{Value in geographic coordinate system} \\ & \text{J} \qquad \text{J} \ \text{The magnitude of star} \\ \end{array}$	D	nie geomagnetic neid vector in geographic	$\mu$	The gravitational constant of the Earth
$\Delta B$ The error between the measurement and estimate geomagnetic field vector $P(J_2)$ Perturbation acceleration caused by $J_2$ (m/s² $B_m$ The measurement geomagnetic field vector $v_L$ The measurement noise of the star sensor (" $F$ The total intensity of geomagnetic field vector (nT) $v_L$ The magnetometer measurement noise (nT) $D$ The declination angle (deg.) $v_B_1$ The magnetometer measurement noise (deg.) $I$ The inclination angle (deg.) $v_{\beta}$ Angle measurement noise (deg.) $J$ The angle between starlight vector and measurement geomagnetic field vector (deg.) $v_B$ Superscripts and subscripts $U$ The starlight vector in star sensor coordinate system $v_{A}$ Estimate value $L_m$ The starlight vector in satellite body coordinate system $v_A$ $v_A$ $f$ = Focal length (mm) $j$ $j$ -th $M_V$ = The magnitude of star $j$ $j$ -th	4.0	Coordinate system	$J_2$	The second zonal coefficient
$B_m$ The measurement geomagnetic field vector $v_L$ The measurement noise of the star sensor (" $B_m$ The measurement geomagnetic field vector $v_L$ The measurement noise of the star sensor (" $F$ The total intensity of geomagnetic field vector (nT) $v_{B1}$ The magnetometer measurement noise (nT) $D$ The declination angle (deg.) $v_B$ Geomagnetic field model noise (nT) $I$ The inclination angle (deg.) $v_{\beta}$ Angle measurement noise (deg.) $J$ The angle between starlight vector and measurement geomagnetic field vector (deg.)Superscripts and subscripts $U$ The starlight vector in star sensor coordinate system $v_{Alue}$ in inertial coordinate system $L_m$ The starlight vector in satellite body coordinate system $v_{Alue}$ in geographic coordinate system $f$ = Focal length (mm) $j$ $j$ -th $M_V$ = The magnitude of star $j$ $j$ -th	$\Delta B$	The error between the measurement and	$P(J_2)$	Perturbation acceleration caused by $J_2$ (m/s <sup>2</sup> )
$B_m$ The measurement geomagnetic field vector $v_{B1}$ The magnetometer measurement noise (nT) $F$ The total intensity of geomagnetic field vector (nT) $v_{B1}$ The magnetometer measurement noise (nT) $D$ The declination angle (deg.) $v_{B1}$ The magnetometer measurement noise (deg.) $I$ The inclination angle (deg.) $v_{B1}$ The magnetometer measurement noise (deg.) $\beta$ The angle between starlight vector and measurement geomagnetic field vector (deg.)Superscripts and subscripts $U$ The starlight vector in star sensor coordinate system $v_{Alue in inertial coordinate systemL_mThe starlight vector in satellite body coordinate systemv_{Alue in geographic coordinate systemf= Focal length (mm)jj-thM_V= The magnitude of starjj-th$	л	estimate geomagnetic field vector	$v_L$	The measurement noise of the star sensor (")
FThe total intensity of geomagnetic field vector (nT) $v_{B2}$ Geomagnetic field model noise (nT) $v_{\beta}$ DThe declination angle (deg.) $v_{\beta}$ Angle measurement noise (deg.)IThe inclination angle (deg.) $v_{\beta}$ Superscripts and subscripts $\beta$ The angle between starlight vector and mea- surement geomagnetic field vector (deg.)Superscripts and subscriptsUThe starlight vector in star sensor coordinate system $\cdot$ Estimate value $L_m$ The starlight vector in satellite body coordi- nate system $\cdot$ Value in inertial coordinate system $n$ f= Focal length (mm) $j$ $j$ -th $M_V$ = The magnitude of star $j$	$B_m$	The measurement geomagnetic field vector	$v_{B1}$	The magnetometer measurement noise (nT)
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	F	The total intensity of geomagnetic field	$v_{B2}$	Geomagnetic field model noise (nT)
DThe declination angle (deg.)Superscripts and subscriptsIThe inclination angle (deg.)Superscripts and subscripts $\beta$ The angle between starlight vector and measurement geomagnetic field vector (deg.)Superscripts and subscriptsUThe starlight vector in star sensor coordinate system $\sim$ Estimate value $L_m$ The starlight vector in satellite body coordinate system $\flat$ Value in inertial coordinate system $f$ = Focal length (mm) $j$ $j$ -th $M_V$ = The magnitude of star $j$ $j$ -th	_	vector (nT)	υβ	Angle measurement noise (deg.)
IThe inclination angle (deg.)Superscripts and subscripts $\beta$ The angle between starlight vector and measurement geomagnetic field vector (deg.)Superscripts and subscriptsUThe starlight vector in star sensor coordinate system $\sim$ Estimate value $L_m$ The starlight vector in satellite body coordinate system $b$ Value in inertial coordinate system $f$ = Focal length (mm) $j$ $j$ -th $M_V$ = The magnitude of star $j$ $j$ -th	D	The declination angle (deg.)	,	
$\beta$ The angle between starlight vector and measurement geomagnetic field vector (deg.)Estimate value $U$ The starlight vector in star sensor coordinate system $i$ Value in inertial coordinate system $L_m$ The starlight vector in satellite body coordinate system $b$ Value in satellite body coordinate system $f$ =Focal length (mm) $j$ $j$ -th $M_V$ =The magnitude of star $d$ $d$	Ι	The inclination angle (deg.)	Superscr	ints and subscripts
surement geomagnetic field vector (deg.) $\sim$ Estimate valueUThe starlight vector in star sensor coordinate systemiValue in inertial coordinate system $L_m$ The starlight vector in satellite body coordi- nate systembValue in satellite body coordinate systemf= Focal length (mm)jj-th $M_V$ = The magnitude of star $J$	β	The angle between starlight vector and mea-	<i>F</i>	<i>i</i>
$U$ The starlight vector in star sensor coordinate system $i$ Value in inertial coordinate system $L_m$ The starlight vector in satellite body coordi- nate system $i$ Value in satellite body coordinate system $f$ =Focal length (mm) $j$ $j$ -th $M_V$ =The magnitude of star $i$ $j$ -th		surement geomagnetic field vector (deg.)	^	Estimate value
system $i$ value in inertial coordinate system $L_m$ The starlight vector in satellite body coordinate system $b$ Value in satellite body coordinate system $n$ $system$ $n$ Value in geographic coordinate system $f$ $=$ Focal length (mm) $j$ $j$ -th $M_V$ $=$ The magnitude of star $i$	U	The starlight vector in star sensor coordinate	:	Value in inertial coordinate system
$L_m$ The starlight vector in satellite body coordinate system $b$ Value in satellite body coordinate system $n$ $n$ Value in geographic coordinate system $f$ $=$ Focal length (mm) $j$ $M_V$ $=$ The magnitude of star		system	l h	Value in catallite body coordinate system
nate system $n$ value in geographic coordinate system $f$ =Focal length (mm) $j$ $j$ -th $M_V$ =The magnitude of star $j$ $j$ -th	$L_m$	The starlight vector in satellite body coordi-	D	Value in satellite body cooluliate system
$ \begin{aligned} f &= \text{Focal length (mm)} & J & J^{-\text{tn}} \\ M_V &= \text{The magnitude of star} \end{aligned} $		nate system	11 ;	value in geographic coordinate system
$M_V$ = The magnitude of star	f	=Focal length (mm)	J	j-tn
	$M_V$	=The magnitude of star		

on the communication with other satellites. In addition, the jamming may also reduce the navigation accuracy of GPS.

Three-axis magnetometers have the advantages of strong independency and no terrain limitation. It can provide all-weather, continuous measurement information. Most of current satellites have used magnetometers for orbit and attitude determination. However, because of the low precision of geomagnetic field models and magnetometers, GNS has low navigation accuracy and should be integrated with other navigation systems.

Similar to GNS, CNS is another environment-sensitive navigation system. For the advantages of good concealment, high directional precision, and no electromagnetic jamming, etc., CNS has been successfully applied in the navigation systems of most spacecrafts. Owing to the emergence of large-view-field star sensors, it becomes possible for CNS to observe the starlights of more than three guidance stars at the same time and achieve high accuracy attitude determination [24–26]. Although CNS has lower data rate, it can serve as a good complement to GNS. The navigation accuracy of GNS/CNS can be enhanced by using the suitable optimal estimation method.

The main goal of this paper is to present a novel autonomous navigation scheme based on the combination of starlight/geomagnetic information. This scheme makes full use of the starlight and geomagnetic field information, and uses UKF to obtain high accuracy navigation parameters for small satellites. This paper consists of six sections. After this introduction, the geomagnetic field model is described in Section 2. The measurement principle of a large-view-field star sensor is explained in Section 3. The system modeling of GNS/CNS is introduced in Section 4, including the development of the state and measurement equations, and the process of UKF. The simulation results are demonstrated in Section 5. Conclusions are drawn in Section 6.

#### 2. Geomagnetic field model

Near-Earth space has abundant geomagnetic field information, and the potential function of geomagnetic Download English Version:

https://daneshyari.com/en/article/1715184

Download Persian Version:

https://daneshyari.com/article/1715184

Daneshyari.com