量化姿態角及訊號傳播之誤差於福爾摩沙衛星三號之軌道求定

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摘要

福爾摩沙衛星三號(FORMOSAT-3/COSMIC, F3/C)發射於 2006 年 4 月 15 日，為台美合作的衛星任務。此任務共有 6 顆微衛星被發射升空，每顆衛星均裝載 2 個 POD GPS 天線。本研究使用 GPS 無差分觀測量與利用減動力法與動態法進行 LEO 軌道的解算，並且將 F3/C 與 GRACE 衛星進行 GPS 觀測量品質分析比較。對於 F3/C 與 GRACE 衛星，其電碼觀測量之多路徑效應的影響分別為 P1 (MP1)，0.77 m 和 0.35 m; P2 (MP2) 1.06 m 和 0.57 m; 週波脫落發生的頻率分別為 1/29 和 1/84; 後驗單位權標準偏差分別為 4 cm 和 1 cm; 動力軌道與動態軌道之差異分別為，10 cm 和 2 cm。

本文進行 F3/C 衛星質量中心(COM)的變化、衛星姿態、GPS 天線相位中心的變化和纜線延遲影響之相關性的研究。在本研究中，nominal 姿態給定出的 F3/C 軌道優於 observed 姿態給定的軌道。數值的測試顯示出，為了不破壞軌道的求定，F3/C 的 COM 必須精準地被率定。 兩條不同的 30 小時軌道弧長被使用於 5 小時和 6 小時之軌道重疊分析，而動力軌道與動態軌道之精度幾近相同，且落於 2-3 cm 的精度。本研究的軌道與 UCAR(near real-time)和 WHU (post-processed)比較，差異大約為 10 cm，其原因為力模式、GPS 軌道與 GPS 時錶改正之不同所致。而本研究的 F3/C 動態軌道將被使用於地球時變重力場之反衍。利用 F3/C GPS 資料進行重力場的求定，仔細的選擇 GPS 資料是必須的。然而由於 F3/C 共有 6 顆衛星，其大量的軌道資料量將可以補足 GPS 資料品質

的缺陷。

而另一個評估定位品質的方法，就是利用量化姿態誤差。姿態轉換矩陣主要用於座標框架之間的轉換，而當中之間的軌道精度損失可能發生於不穩定的姿態控制時段。使用時間段 DOY 118 to 336, 2008 的 GPS 資料進行評估， 可得 F3/C 定位精度依序為 FM1 (2.72 cm), FM2 (2.62 cm), FM3 (2.37 cm), FM4 (1.90 cm), FM5 (1.70 cm), and FM6 (1.99 cm).

Quantification of attitude error and signal propagation error in the GPS orbit determination of FORMOSAT-3/COSMIC

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Abstract

The joint Taiwan-US mission FORMOSAT-3/COSMIC (F3/C) was launched on April 15, 2006. Each of the six satellites is equipped with two precise orbit determination (POD) antennas. The POD antennas of F3/C and GRACE-A satellites are from the same manufacturer, but are installed in different configurations. The LEO satellites are determined from GPS data using undifference carrier-phase measurements by the reduced dynamic and kinematic methods. This study compares the qualities of GPS observables from F3/C and GRACE. Using selected satellites and time spans, the following average values for the satellite F3/C and satellite A of GRACE are obtained: multipath effect on the pseudorange P1 (MP1), 0.77 m and 0.35 m; multipath effect on the pseudorange P2 (MP2), 1.06 m and 0.57 m; occurrence frequency of cycle slip, 1/29 and 1/84; standard error of unit weight, 4 cm and 1 cm; dynamic-kinematic orbit difference, 10 cm and 2 cm.

The effects of satellite center of mass (COM) variation, satellite attitude, GPS antenna phase center variation (PCV), and cable delay difference on the F3/C orbit determination are studied. Nominal attitudes estimated from satellite state vectors deliver a better orbit accuracy when compared to observed attitude. Numerical tests show that the F3/C COM must be precisely calibrated in order not to corrupt orbit determination. Based on the analyses of the 5-h and 6-h orbit overlaps of two 30-h arcs, orbit accuracies from the reduced dynamic and

kinematic solutions are nearly identical and are at the 2-3 cm level. The mean RMS difference between the orbits from this study and those from UCAR (near real-time) and WHU (post-processed) is about 10 cm, which is largely due to different uses of GPS ephemerides, high-rate GPS clocks and force models. The kinematic orbits of F3/C are expected to be used for recovery of temporal variations in the gravity field. For gravity determination using F3/C GPS data, a careful selection of GPS data is critical. With six satellites in orbit, F3/C's large amount of GPS data will make up the deficiency in data quality

An alternative assessment of the positioning quality is made by propagating attitude error to orbit error. The attitude transformation matrix is responsible for coordinate frame conversions, and a degraded orbit accuracy in the F3/C satellites might occur under an unstable attitude control. This assessment, using GPS data of DOY 118 to 336, 2008, leads to the following 3-D positioning accuracies: 2.72, 2.62, 2.37, 1.90, 1.70, and 1.99 cm for FM1, …, and FM6.

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Acronyms

ACS	Attitude Control System
ADCS	Attitude Determination and Control System
ARS	Attitude Reference System
ATM	Attitude Transformation Matrix
BRE	Broad Reach Engineering
C/N0	Carrier-to-Noise ratio
CHAMP	Challenging Minisatellite Payload
CODE	Center for Orbit Determination in Europe
COM	Center Of Mass
ESA	European Space Agency
F3/C	FORMOSAT-3/COSMIC
GOCE	Gravity field and steady-state Ocean Circulation Explorer
GOX	GPS Occultation Experimental Receiver
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
HRC	High-Rate Clock
IGOR	Integration GPS and Occultation Receiver
IGS	International GNSS Service
IOD	Ionospheric Delay
JPL	Jet Propulsion Laboratory
KBR	K-Band Ranging
LEO	Low Earth Orbiter
LVLH	Local Vertical-Local Horizontal
MIT	Massachusetts institute of Technology

NRCan	Natural Resources Canada
NRL	Naval Research Laboratory
NRT	Near-Real Time
NSPO	National Space Organization
PCO	Phase Center Offset
PCV	Phase Center Variation
POD	Precise Orbit Determination
PPP	Precise Point Positioning
QC	Quality Check
RINEX	Receiver Independent Exchange
SAD	Solar Array Drive
SLR	Satellite Laser Ranging
STD	Standard Deviation
TBB	Tri-Band Beacon
TEC	Total Electron Content
TEQC	Translation, Editing and Quality Checking
TIP	Tiny Ionospheric Photometer
UCAR	University Corporation for Atmospheric Research