

Operational Aspects of Orbit Determination with GPS for Small Satellites with SAR Payloads

Sergio De Florio, Tino Zehetbauer, Dr. Thomas Neff
Phone: +498153282357, Sergio.DeFlorio@dlr.de

Abstract

Scientific small satellite missions for remote sensing with Synthetic Aperture Radar (SAR) payloads or high accuracy optical sensors, pose very strict requirements on the accuracy of the reconstructed satellite positions, velocities and accelerations. Today usual GPS receivers can fulfill the accuracy requirements of this missions in most cases, but for low-cost-missions the decision for a appropriate satellite hardware has to take into account not only the reachable quality of data but also the costs. An analysis is carried out in order to assess which on board and ground equipment, which type of GPS data and processing methods are most appropriate to minimize mission costs and full satisfying mission payload requirements focusing the attention on a SAR payload.


Requirements

Taylor expansion of the phase Φ of the radar signal as a function of time varying position, velocity and acceleration:

$$\Phi(t) = \frac{4\pi}{\lambda} R(t) = a_0(p_k) + a_1(p_k)(t-t_0) + a_2(p_k)(t-t_0)^2 + a_3(p_k)(t-t_0)^3 + o(t^3)$$

Typical requirements, for 0.5 to 1.0 m image resolution, on spacecraft position vector x :

$$x \leq 15 \text{ m} \quad \dot{x} \leq 1.5 \cdot 10^{-2} \text{ m/s} \quad \ddot{x} \leq 6.0 \cdot 10^{-4} \text{ m/s}^2 \quad (3\sigma)$$

 These are requirements on the measurements, not on the real motion of the satellite

Required Hardware

GPS hardware

Manufacturer	Receiver	Channels / Frequencies / Codes	Mission
Magellan	GPSAC	2/L1, L2/GA, P	Lowland Landmark
Navstar	GPSR	8/L1, L2/GA, P	ESOC, ZEPHYRUS, OREX
	TANS	8/L1/GA	Space Shuttle, Poles, FARM-ARA, GAGE/STEP/CREST
	TANS Quattro	8/L1/GA	FAOCLA
Trimble Navigation	TANS	8/L1/GA	GPS/INS/PRN, GSCOM/FPS, Shyren, VES, TCMR, LORAN, FARM-Bore, AODON
	TANS Heavy	8/L1/GA	ARCS, GAGE, FARM, GAGE/STEP, GAGE/STEP-2, ARSAT Phase 20, TRAC, OREX, GAGE/STEP, GAGE/STEP-2
Avantronic	GPSR	8/L1/GA	COSECO/SPASAT
Adrianich	Adrianich GPSR	24/L1/GA	COMET
Hitachi	GPS	12/L1/GA	STEP-1
Hitachi	GPSR	8/L1/GA	ESU
Allen Osborne Associates, Inc.	TurboStar	8/L1, L2/ambigu	FAOCLA, GAGE/STEP, GAGE/STEP-2, GAGE/STEP-3, GAGE/STEP-4, GAGE/STEP-5, GAGE/STEP-6, GAGE/STEP-7, GAGE/STEP-8, GAGE/STEP-9, GAGE/STEP-10, GAGE/STEP-11, GAGE/STEP-12, GAGE/STEP-13, GAGE/STEP-14, GAGE/STEP-15, GAGE/STEP-16, GAGE/STEP-17, GAGE/STEP-18, GAGE/STEP-19, GAGE/STEP-20, GAGE/STEP-21, GAGE/STEP-22, GAGE/STEP-23, GAGE/STEP-24, GAGE/STEP-25, GAGE/STEP-26, GAGE/STEP-27, GAGE/STEP-28, GAGE/STEP-29, GAGE/STEP-30, GAGE/STEP-31, GAGE/STEP-32, GAGE/STEP-33, GAGE/STEP-34, GAGE/STEP-35, GAGE/STEP-36, GAGE/STEP-37, GAGE/STEP-38, GAGE/STEP-39, GAGE/STEP-40, GAGE/STEP-41, GAGE/STEP-42, GAGE/STEP-43, GAGE/STEP-44, GAGE/STEP-45, GAGE/STEP-46, GAGE/STEP-47, GAGE/STEP-48, GAGE/STEP-49, GAGE/STEP-50, GAGE/STEP-51, GAGE/STEP-52, GAGE/STEP-53, GAGE/STEP-54, GAGE/STEP-55, GAGE/STEP-56, GAGE/STEP-57, GAGE/STEP-58, GAGE/STEP-59, GAGE/STEP-60, GAGE/STEP-61, GAGE/STEP-62, GAGE/STEP-63, GAGE/STEP-64, GAGE/STEP-65, GAGE/STEP-66, GAGE/STEP-67, GAGE/STEP-68, GAGE/STEP-69, GAGE/STEP-70, GAGE/STEP-71, GAGE/STEP-72, GAGE/STEP-73, GAGE/STEP-74, GAGE/STEP-75, GAGE/STEP-76, GAGE/STEP-77, GAGE/STEP-78, GAGE/STEP-79, GAGE/STEP-80, GAGE/STEP-81, GAGE/STEP-82, GAGE/STEP-83, GAGE/STEP-84, GAGE/STEP-85, GAGE/STEP-86, GAGE/STEP-87, GAGE/STEP-88, GAGE/STEP-89, GAGE/STEP-90, GAGE/STEP-91, GAGE/STEP-92, GAGE/STEP-93, GAGE/STEP-94, GAGE/STEP-95, GAGE/STEP-96, GAGE/STEP-97, GAGE/STEP-98, GAGE/STEP-99, GAGE/STEP-100
General Dynamics	Wainey	12/L1/GA	FAOCLA, GAGE/STEP, GAGE/STEP-2, GAGE/STEP-3, GAGE/STEP-4, GAGE/STEP-5, GAGE/STEP-6, GAGE/STEP-7, GAGE/STEP-8, GAGE/STEP-9, GAGE/STEP-10, GAGE/STEP-11, GAGE/STEP-12, GAGE/STEP-13, GAGE/STEP-14, GAGE/STEP-15, GAGE/STEP-16, GAGE/STEP-17, GAGE/STEP-18, GAGE/STEP-19, GAGE/STEP-20, GAGE/STEP-21, GAGE/STEP-22, GAGE/STEP-23, GAGE/STEP-24, GAGE/STEP-25, GAGE/STEP-26, GAGE/STEP-27, GAGE/STEP-28, GAGE/STEP-29, GAGE/STEP-30, GAGE/STEP-31, GAGE/STEP-32, GAGE/STEP-33, GAGE/STEP-34, GAGE/STEP-35, GAGE/STEP-36, GAGE/STEP-37, GAGE/STEP-38, GAGE/STEP-39, GAGE/STEP-40, GAGE/STEP-41, GAGE/STEP-42, GAGE/STEP-43, GAGE/STEP-44, GAGE/STEP-45, GAGE/STEP-46, GAGE/STEP-47, GAGE/STEP-48, GAGE/STEP-49, GAGE/STEP-50, GAGE/STEP-51, GAGE/STEP-52, GAGE/STEP-53, GAGE/STEP-54, GAGE/STEP-55, GAGE/STEP-56, GAGE/STEP-57, GAGE/STEP-58, GAGE/STEP-59, GAGE/STEP-60, GAGE/STEP-61, GAGE/STEP-62, GAGE/STEP-63, GAGE/STEP-64, GAGE/STEP-65, GAGE/STEP-66, GAGE/STEP-67, GAGE/STEP-68, GAGE/STEP-69, GAGE/STEP-70, GAGE/STEP-71, GAGE/STEP-72, GAGE/STEP-73, GAGE/STEP-74, GAGE/STEP-75, GAGE/STEP-76, GAGE/STEP-77, GAGE/STEP-78, GAGE/STEP-79, GAGE/STEP-80, GAGE/STEP-81, GAGE/STEP-82, GAGE/STEP-83, GAGE/STEP-84, GAGE/STEP-85, GAGE/STEP-86, GAGE/STEP-87, GAGE/STEP-88, GAGE/STEP-89, GAGE/STEP-90, GAGE/STEP-91, GAGE/STEP-92, GAGE/STEP-93, GAGE/STEP-94, GAGE/STEP-95, GAGE/STEP-96, GAGE/STEP-97, GAGE/STEP-98, GAGE/STEP-99, GAGE/STEP-100
Space Systems/Loral	Tweezer	8/L1/GA	STEP-1, STEP-2, STEP-3, STEP-4, STEP-5, STEP-6, STEP-7, STEP-8, STEP-9, STEP-10, STEP-11, STEP-12, STEP-13, STEP-14, STEP-15, STEP-16, STEP-17, STEP-18, STEP-19, STEP-20, STEP-21, STEP-22, STEP-23, STEP-24, STEP-25, STEP-26, STEP-27, STEP-28, STEP-29, STEP-30, STEP-31, STEP-32, STEP-33, STEP-34, STEP-35, STEP-36, STEP-37, STEP-38, STEP-39, STEP-40, STEP-41, STEP-42, STEP-43, STEP-44, STEP-45, STEP-46, STEP-47, STEP-48, STEP-49, STEP-50, STEP-51, STEP-52, STEP-53, STEP-54, STEP-55, STEP-56, STEP-57, STEP-58, STEP-59, STEP-60, STEP-61, STEP-62, STEP-63, STEP-64, STEP-65, STEP-66, STEP-67, STEP-68, STEP-69, STEP-70, STEP-71, STEP-72, STEP-73, STEP-74, STEP-75, STEP-76, STEP-77, STEP-78, STEP-79, STEP-80, STEP-81, STEP-82, STEP-83, STEP-84, STEP-85, STEP-86, STEP-87, STEP-88, STEP-89, STEP-90, STEP-91, STEP-92, STEP-93, STEP-94, STEP-95, STEP-96, STEP-97, STEP-98, STEP-99, STEP-100
Boresis	TIGRES	24/L1/GA	FAOCLA, GAGE/STEP, GAGE/STEP-2, GAGE/STEP-3, GAGE/STEP-4, GAGE/STEP-5, GAGE/STEP-6, GAGE/STEP-7, GAGE/STEP-8, GAGE/STEP-9, GAGE/STEP-10, GAGE/STEP-11, GAGE/STEP-12, GAGE/STEP-13, GAGE/STEP-14, GAGE/STEP-15, GAGE/STEP-16, GAGE/STEP-17, GAGE/STEP-18, GAGE/STEP-19, GAGE/STEP-20, GAGE/STEP-21, GAGE/STEP-22, GAGE/STEP-23, GAGE/STEP-24, GAGE/STEP-25, GAGE/STEP-26, GAGE/STEP-27, GAGE/STEP-28, GAGE/STEP-29, GAGE/STEP-30, GAGE/STEP-31, GAGE/STEP-32, GAGE/STEP-33, GAGE/STEP-34, GAGE/STEP-35, GAGE/STEP-36, GAGE/STEP-37, GAGE/STEP-38, GAGE/STEP-39, GAGE/STEP-40, GAGE/STEP-41, GAGE/STEP-42, GAGE/STEP-43, GAGE/STEP-44, GAGE/STEP-45, GAGE/STEP-46, GAGE/STEP-47, GAGE/STEP-48, GAGE/STEP-49, GAGE/STEP-50, GAGE/STEP-51, GAGE/STEP-52, GAGE/STEP-53, GAGE/STEP-54, GAGE/STEP-55, GAGE/STEP-56, GAGE/STEP-57, GAGE/STEP-58, GAGE/STEP-59, GAGE/STEP-60, GAGE/STEP-61, GAGE/STEP-62, GAGE/STEP-63, GAGE/STEP-64, GAGE/STEP-65, GAGE/STEP-66, GAGE/STEP-67, GAGE/STEP-68, GAGE/STEP-69, GAGE/STEP-70, GAGE/STEP-71, GAGE/STEP-72, GAGE/STEP-73, GAGE/STEP-74, GAGE/STEP-75, GAGE/STEP-76, GAGE/STEP-77, GAGE/STEP-78, GAGE/STEP-79, GAGE/STEP-80, GAGE/STEP-81, GAGE/STEP-82, GAGE/STEP-83, GAGE/STEP-84, GAGE/STEP-85, GAGE/STEP-86, GAGE/STEP-87, GAGE/STEP-88, GAGE/STEP-89, GAGE/STEP-90, GAGE/STEP-91, GAGE/STEP-92, GAGE/STEP-93, GAGE/STEP-94, GAGE/STEP-95, GAGE/STEP-96, GAGE/STEP-97, GAGE/STEP-98, GAGE/STEP-99, GAGE/STEP-100
JPL	MicroGPS	12/L1/GA	ENAC
Sony Satellite Technology	SDR-1B	24/L1/GA	Tweezer
	SDR-2B	24/L1/GA	UNISTAR
Rockwell - Collins Avionics and Communications Division	ASTV	8(L1 com, 2 amb) / L1 / L2 / GA or P	CHAMP/STEP, STEP-2
Rockwell Collins	GDM-S	5/L1/GA or P	ESU
JPL/Spacecraft Avionics	Avionics (Rockwell)	48/L1, L2/GA, P, ambigu	STEP, STEP-C, SAC-C, CHAMP, Jason-1, VCL, GAGE/STEP, GAGE/STEP-2, GAGE/STEP-3, GAGE/STEP-4, GAGE/STEP-5, GAGE/STEP-6, GAGE/STEP-7, GAGE/STEP-8, GAGE/STEP-9, GAGE/STEP-10, GAGE/STEP-11, GAGE/STEP-12, GAGE/STEP-13, GAGE/STEP-14, GAGE/STEP-15, GAGE/STEP-16, GAGE/STEP-17, GAGE/STEP-18, GAGE/STEP-19, GAGE/STEP-20, GAGE/STEP-21, GAGE/STEP-22, GAGE/STEP-23, GAGE/STEP-24, GAGE/STEP-25, GAGE/STEP-26, GAGE/STEP-27, GAGE/STEP-28, GAGE/STEP-29, GAGE/STEP-30, GAGE/STEP-31, GAGE/STEP-32, GAGE/STEP-33, GAGE/STEP-34, GAGE/STEP-35, GAGE/STEP-36, GAGE/STEP-37, GAGE/STEP-38, GAGE/STEP-39, GAGE/STEP-40, GAGE/STEP-41, GAGE/STEP-42, GAGE/STEP-43, GAGE/STEP-44, GAGE/STEP-45, GAGE/STEP-46, GAGE/STEP-47, GAGE/STEP-48, GAGE/STEP-49, GAGE/STEP-50, GAGE/STEP-51, GAGE/STEP-52, GAGE/STEP-53, GAGE/STEP-54, GAGE/STEP-55, GAGE/STEP-56, GAGE/STEP-57, GAGE/STEP-58, GAGE/STEP-59, GAGE/STEP-60, GAGE/STEP-61, GAGE/STEP-62, GAGE/STEP-63, GAGE/STEP-64, GAGE/STEP-65, GAGE/STEP-66, GAGE/STEP-67, GAGE/STEP-68, GAGE/STEP-69, GAGE/STEP-70, GAGE/STEP-71, GAGE/STEP-72, GAGE/STEP-73, GAGE/STEP-74, GAGE/STEP-75, GAGE/STEP-76, GAGE/STEP-77, GAGE/STEP-78, GAGE/STEP-79, GAGE/STEP-80, GAGE/STEP-81, GAGE/STEP-82, GAGE/STEP-83, GAGE/STEP-84, GAGE/STEP-85, GAGE/STEP-86, GAGE/STEP-87, GAGE/STEP-88, GAGE/STEP-89, GAGE/STEP-90, GAGE/STEP-91, GAGE/STEP-92, GAGE/STEP-93, GAGE/STEP-94, GAGE/STEP-95, GAGE/STEP-96, GAGE/STEP-97, GAGE/STEP-98, GAGE/STEP-99, GAGE/STEP-100
LEICA Geosystems	Leitax	24/L1, L2/GA	SAC-C
ESA	GPSR	12/L1, L2/GA	INSPIRE
Raytheon Communications Company, Inc.	Nav/Power receiver	12/L1/GA	INSPIRE
ESOC Avionics	Navstar GPS/ARSS	8/L1/GA	

On-board data sampling and storage

Data Type	Sampling Rate	MB/hour to be stored on-board
Navigation solutions and ancillary data	1.0 Hz	1.0
Raw data and ancillary data	1.0 Hz	5.0

Typical Position Accuracies

Raw data based POD strategies

Data Type	Processing Scheme	Accuracy (m)
Single frequency PR	Kinematic	9.1
Single frequency SPP	Reduced-dynamic	0.8
Single frequency PR	Reduced-dynamic	0.8
Single frequency PR & CP	Reduced-dynamic	0.3
Dual frequency PR	Kinematic	2.9
Dual frequency SPP	Reduced-dynamic	0.3
Dual frequency PR	Reduced-dynamic	0.2
Dual frequency PR & CP	Reduced-dynamic	0.1

PR: pseudorange, CP: carrier phase, SPP: single point positions

Navigation solutions based POD strategies

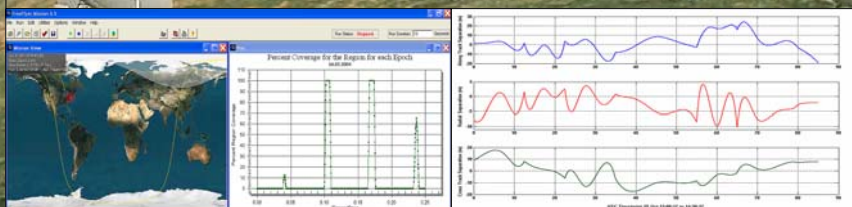
Data Type	Processing Scheme	Accuracy (m)
Navigation solutions	Kinematic	16.5
Navigation solutions	Reduced-dynamic	1.6

Achievable position accuracies for the CHAMP satellite


Orbit Determination Software

Commercial: FreeFlyer by a.i. Solutions (NS), OD Tools Kit by AGI (NS & PR), Bernese Software (NS Raw Data) **Freeware:** GAMIT/GLOBK, GIPSY-OASIS II, Trimble Geomatics (TGO)

GPS navigation-solution based orbit determination with FreeFlyer COTS product



Accuracy	
Position	1.0 m
Velocity	10 ⁻³ m/s
Acceleration	10 ⁻⁶ m/s ²

 The requirement on the acceleration can be fulfilled with the only use of the navigation solutions without any margin and without a 3σ standard deviation.