Pushing the Boundaries of Orbit Determination: GOCE, EGNOS, SCTV & AutoBAHN

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Orbit determination

• LogicaCMG often provides orbit determination solutions when the application is extreme in some way, e.g.:
  – performance limited
  – ultra-precise
  – safety critical

• the following examples illustrate the techniques and tools adopted for a range of recent cases:
  – the EGNOS check-set (performance limited)
  – the GOCE SSTI PDS (ultra-precise)
  – the SCTV Kourou range safety system (safety critical)

• company-funded R&D is undertaken to maintain our expertise, illustrated by the *AutoBAHN* project being undertaken as part of the UK’s Pinpoint programme
EGNOS: showing twin Check Sets at each Facility
Role of the Check Set

- The Processing Set calculates ionospheric, ephemeris and clock corrections and their estimated bounds.
- The Check Set verifies the correctness of this information via independent calculations - uses different data & algorithms.
- The Check Set is the source of EGNOS’s “integrity” information, arguably its most important added value.
- Integrity is critical to enable aviation to use EGNOS as a primary source of navigation information - hence the Check Set was developed to the highest safety-related levels of any EGNOS subsystem.
Check Set technology

- Hardware and system software had to be:
  - acceptable to aviation certification authorities
  - different from the Processing Set
- Concurrent Intel Pentium CPU boards - processing of various data streams shared between the boards
- Software development was in ANSI C
- DO-178b standards were the basis for the project - at level B
Check Set Processing

Processing Set

CS

CKAOp3

CKAOp2

CKAOp1

RIMS

NOF SIS GEO 3

NOF SIS GEO 2

NOF SIS GEO 1

Pre-proc data, Clock biases, Satellite pos

Delta Clock Biases

Meas, Nav Data

Pre&Val

NM/DU Flags Transition Information

CKBOp3

CKBOp2

CKBOp1

NLES Feedback

Integrity Flag

QoS

Pre-proc data, Clock biases, Satellite pos

Internal NOF

Pre&Val

NOF Up per GEO

Integrity Flag

QoS

Integrity Flag

NLES Feedback
EGNOS Performance

• Navigation performance is carefully optimised for both:
  – low false alarm rate (high availability)
  – conservative error bounds (high integrity)

• the implementation processing steps have to meet tight and rigid timing bounds, e.g.:
  – check before transmission: 40msec - achieved: 15msec
  – check after transmission: 500msec - achieved: 280msec
Check Set - future relevance

• The Check Set is the only source of information inside EGNOS on clock performance at many RIMS stations

• the Check Set provides a robust approach for determining system errors in the absence of detailed dynamic information

• the first GSTB-V2 satellite may require support of this type in order to verify its performance
Two active instruments on board:

- electrostatic gravity gradiometer (EGG)
- satellite to satellite tracking instrument (SSTI)
- 12 channel GPS receiver
- Laser retroreflector

GOCE mission concept
Gravity field & steady-state Ocean Circulation earth Explorer

GPS - Satellites
SST - hl
SGG
Earth
mass anomaly
• We are developing the Instrument Processing Facility for the SSTI as part of the GOCE Payload data System (PDS)

• the PDS prime-contractor is Advanced Computer Systems (www.acsys.it)

• the SSTI algorithms are being provided by IAPG (www.goce-projektbuero.de)

• the PDS produces level 1-b products, which include GOCE position and velocity, and associated environmental and error parameters

• these data are provided to scientists for use in gravity field, geoid and other geophysical investigations - hence the need for precision

• the technology includes UML design using either Artisan or EA tools, Dell PCs, Linux, C
• SCTV* is the system used by the Flight Safety Officers at Kourou to monitor the safety of all proposed and actual Ariane trajectories

• radar measurements are used to determine the launcher trajectory and to detect dangerous situations in real-time (onboard telemetry from the launcher is also processed for comparison)

• the algorithms were developed using data from previous flights and from simulated deviating flights

• before each flight SCTV is used to set the boundaries of the allowable trajectory by modelling the dispersion of explosion fragments & fumes

• the operational system was implemented using safety-related development techniques

* SCTV = systeme pour coordination, traitement et visualisation
SCTV technology

- Compaq Alpha servers and workstations selected on the basis of a price versus performance evaluation
- Hardware architecture comprises two independent processing chains exploiting the independence of multiple radar stations
- All new software was written in a carefully controlled sub-set of Ada - HOOD supported by Concerto’s CASE tool for design
- A safety analysis identified the most critical code
- The AdaTest tool was used to instrument the code and provide a framework for test script production
- Testing involved full code, branch and condition coverage - FAGAN inspection techniques used for design review
- PV-Wave was used to compare the results from the prototype and the operational system
AutoBAHN

• AutoBAHN is intended as part of a long term (10-15 years) drive to provide real-time positioning anywhere anytime to millimetre accuracy based on low-cost receivers with GSM, 3G, internet, or satellite for reception of integrity data, GNSS orbits, clock corrections, tropospheric and ionospheric corrections, etc

• 3 year collaboration between Geomatics Dept at Univ of Newcastle and LogicaCMG

• funding provided 50/50 by the UK Eng & Ph Sc Research Council and by LogicaCMG, within the Pinpoint Government/industry GNSS R&D collaborative programme (www.pinpoint-faraday.org.uk)

• the objectives to be realised in the 3 year time-frame of this study are enhanced real-time accuracy with GPS augmented by EGNOS

• the work is intended to assist with exploitation of the Galileo prototype satellite, GSTB-V2
• The project will be based on the GPS software BAHN in operational use at ESOC/ESA.

• reasons for using BAHN include:
  – alternative available software is inadequate for the task
  – long-term objectives need a geodetic quality software with operational status
  – builds on prior UK funding of BAHN through ESA
  – proven record of BAHN in IGS work (orbits, ultra-rapid orbits, clock corrections, TEC, Earth rotation parameters etc) demonstrates its state-of-the-art status for operational-class software
  – long history of LogicaCMG in developing and using BAHN at ESOC
  – BAHN is freely available within Europe
  – major enhancement to BAHN within this project will transfer the IPR for application to other projects with associated technical lead over other European countries
Development lifecycle

• For novel missions, projects or applications it is often useful to distinguish between algorithm development and system implementation

• R&D organisations are often best equipped to define/refine algorithms, while industry has experience of delivering operational systems

• organisations that defined algorithm for these projects:
  – EGNOS check set: IfEN
  – GOCE: IAPG (TU München)
  – SCTV: Onera
  – AutoBAHN: Newcastle Univ
Conclusions

• Orbit determination is moving centre stage in Europe’s space programmes as Galileo builds up momentum

• industry’s work at ESOC over the past 25 years has helped to create a reservoir of capability that is now being deployed on the new programmes

• a mix of scientific institutes and the software industry is able to provide advanced orbit and geophysical determination systems on an operational basis