Single base RTK solutions obtained individually with Galileo and BeiDou as well as in combination with other fully operational GNSS.
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Introduction:
- Real Time Kinematic: Single-base & Networked
- GPS & GLONASS: Fully Operational GNSSes
- Galileo & Beidou: still under construction
- In 2006 some leading manufacturers (Leica, Topcon, Trimble) started a production of receivers with a capability of tracking Galileo (GIOVE) satellites
- Today, almost all recently produced GNSS receivers support a tracking of Galileo (GAL) and BeiDou (BEI) satellites
- A possibility and feasibility of GAL and BEI systems for single-base RTK positioning has been tested (assessed) and presented
Current status of GNSSes:
• GPS (first launch in 1978; FOC in 1995)
  • 31 satellites (12 Block IIR, 7 Block IIR-M, 12 Block F)
  • CDMA (L1, L2, L5); next generation Block III (L1C)
• GLONASS (first launch in 1982; FOC in 1996, again in 2011)
  • 23 satellites (GLONASS-M, GLONASS-K)
  • FDMA (CDMA on GLONASS-K)
Current status of GNSSes:

- **GALILEO** (first launch in 2005; 2008 (GIOVE A&B);
  - FOC started in 2014 expected to be completed by 2020)
  - 22 satellites (14 usable, 2 testing, 4 under commissioning, 2 not usable/available)
- **BeiDou**
  - 28 satellites (15 included in operational constellation (BeiDou-2); 13 not included in operational constellation (BeiDou-3)
  - FOC by 2020 (5 GEO, 3 IGSO, 27 MEO)
Real Time Kinematic (RTK):
- Single base RTK (10-20 km for rapid and reliable ambiguity resolution)
  - TTFA depends on a distance-dependent biases (iono, tropo, orbit)
- Network RTK (distance-dependent biases are modelled)
  - CROPOS
CROatian Position System (CROPOS):

- 33 national GNSS stations + 18 GNSS station from neighbouring networks
- ~ 70 km
- established in 12/2008
- DPS, Highly Precise Positiong Service (HPPS); Geodetic Precise Positiong Sservice (GPPS)
- VRS concept implementing Trimble’s solution
- Currently CROPOS supports GPS and GLONASS observations
- GPPS was used for geodetic network establishment
Geodetic Network and Static GNSS observations:
• 6 stations (S1, P1, P2, P3, S2, B)
• Static observations at S2 and B for 44 min
• CROPOS GPPS (Rinex 3.02): 3 VRS
• Topcon Magnet Office Tools
• (E, N, h)
• $\sigma (E) = 3 \text{ mm}; \sigma (N) = 3 \text{ mm}; \sigma (h) = 6 \text{ mm}$
• Topcon Hiper SR (station S2) & Hiper HR (station B)
RTK measurements:

- GNSS receivers (base & rover) with a capability of tracking and positioning using GALILEO and BeiDou satellites
- Tracking vs. Positioning
- 2x Topcon Hiper HR (452 channels)
- FC-5000 controller with installed TRU
- Topcon Receiver Utility (TRU)
- Single-base RTK
- Topcon’s LongLink
GNSS planning

- **GNSS Planning Online tool**
  [http://www.trimble.com/GNSSPlanningOnline](http://www.trimble.com/GNSSPlanningOnline)

- 2x Topcon Hiper HR receiver were available for two consecutive days: August 23th and 24th 2017.
- Planning has involved Galileo and BeiDou satellites only
- GPS (visible 8-12 SV)
- GLONASS (visible 6-10 SV)
RTK positioning:
• August 23\textsuperscript{th} and 24\textsuperscript{th} 2017
• Static observations $\rightarrow$ accuracy assessment
• Two consecutive days $\rightarrow$ precision assessment
• Base GNSS receiver set up on tripod
• Rover GNSS receiver on the range pole
• Base receiver started by TRU running on FC-5000 controller (set to track all visible and available satellites);
RTCM 3.02 via LongLing Bluetooth connection

13 different satellite system combinations:
1. GPS+GLO+GAL+BEI (GGGB)
2. GPS+GLO+GAL (GPS.GLO.GAL)
3. GPS+GLO+BEI (GPS.GLO.BEI)
4. GPS+GAL+BEI (GPS.GAL.BEI)
5. GLO+GAL+BEI (GLO.GAL.BEI)
6. GPS+GLO (GPS.GLO)
7. GPS+BEI (GPS.BEI)
8. GPS+GAL (GPS.GAL)
9. GLO+BEI (GLO.BEI)
10. GLO+GAL (GLO.GAL)
11. GAL+BEI (GAL.BEI)
12. GAL only (GAL)
13. BEI only (BEI)
• Depending on the selected GNSS constellation combination, on the rover receiver with the TRU SW the chosen satellite systems were turned on or off and the observation taken.

• Photos of the FC-5000 display showing RTK positioning results were captured simulating the recording of three consecutive epochs.
RTK measurement results:

• The photos were systematically named and stored, taking care about GNSS constellation combination
• Ellipsoidal coordinates along with the PDOP, HRMS, VRMS were typed in Excell spreadsheet
• The most vulnerable step → special attention was paid including multiple checks
• \((\varphi, \lambda, h) \rightarrow \text{Magnet Office Tools} \rightarrow (E, N, h)\)
• Accuracy and Precision estimation enabled
RTK accuracy estimation (2D):
- Static observations (B, S2)
- $\Delta = $ Measured – Reference
- August 23$^{\text{th}}$ 2017 (all combination provided a FIXED solution) (2D): 4 to 16 mm (AVE 13 mm)
- August 24$^{\text{th}}$ 2017 (BEI only combination with Autonomous solution) (2D): 8 to 43 mm (AVE 17 mm)
RTK accuracy estimation (h):

- Static observations (B, S2)
- $\Delta = \text{Measured} - \text{Reference}$
- August 23\textsuperscript{th} 2017 (all combination provided a FIXED solution) (h): -7 mm to 42 mm (RMS 13 mm)
- August 24\textsuperscript{th} 2017 (BEI only combination with Autonomous solution) (h): 1 mm to 55 mm (RMS 22 mm)
RTK precision estimation (23th vs 24th August):

• Each GNSS constellation combination results are compared among two consecutive days of observation

• 2D: 0 to 43 mm (RMS 14 mm)
  largest differences obtained from GAL only (43 mm) and GAL.BEI combination (17 mm)

• Δh: -14 mm to +48 mm (RMS: 21 mm)
  largest differences obtained from GAL.BEI (48 mm) and GAL only (39 mm)

• CONCLUSION: combinations including at least on fully operational GNSS (GPS or GLONASS) can provide consecutive results within 2 cm
CONCLUSIONS:

• Single base RTK results obtained with 13 GNSS constellation combinations
• Individual and joint combinations consisting of observation data of systems under construction (Galileo and BeiDou)
• Exclusion of GPS observations from RTK solution (enabling individual solutions) has been carried out by TRU SW running on field controller
• Planning tool has pointed out optimal time windows allowing individual (GAL, BEI) solutions
• For reliable RTK positioning results (2 cm (2D) & (h)) the usage of at least one fully operational GNSS is needed
• Results obtained with few constellations (3 or 4) haven’t shown a significant improvement in terms of accuracy and precision.
REMARK:

- This paper has been compiled from the students’ publication rewarded with the Dean’s Awards of the Faculty of Geodesy for the academic year 2016/2017.
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