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Outline

• Part I
  – Background and Introduction to RTQC

• Part II
  – Testing (RTQC Mobile & Quality Indicators)

• Part III
  – Quality Indicators and Stochastic Modelling

• Conclusions and Future Work
Part I

Background and Introduction to RTQC

Project Background

• Use of high accuracy GNSS has increased markedly in the last decade
• Range of applications has grown beyond surveying & engineering
• Facilitated by CORS Networks and Network RTK
• Critical decisions based on GNSS have increased as a result
• Challenges for CORS provider, manufacturers, researchers
Project Background

- Ensuring GNSS derived positions are
  - High quality
  - Dependable
  - Fit-for-purpose

- Current Quality indicators are not always reliable
- Generally a measure of precision is conveyed
  - Often overestimated
  - Precision is not accuracy

Examples

<table>
<thead>
<tr>
<th>GPS POS</th>
<th>PM352 VG_GNSS</th>
<th>WGS-84 lat</th>
<th>37°41'36.5264377&quot;</th>
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<th>144°55'58.513271&quot;</th>
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<tr>
<td>Normal</td>
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<td>GPS QC1</td>
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<td>Relative DOP: Yes</td>
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<td>1.7</td>
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<td>4.5</td>
<td>RMS</td>
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<td>Hori std deviation</td>
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<td>Vert std deviation</td>
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<td>End sec: 1566</td>
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<td>Lost</td>
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<tr>
<td>Survey type</td>
<td></td>
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<td>Real Time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plate geodetic</td>
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</tr>
<tr>
<td>POINT DESIGN</td>
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<td></td>
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<tr>
<td>Gained</td>
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<tr>
<td>Survey type</td>
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<td>Real Time</td>
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<tr>
<td>Plate geodetic</td>
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</table>
Examples

### Point Derivations

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>B6</td>
</tr>
<tr>
<td>RMS</td>
<td>0.003m</td>
</tr>
<tr>
<td>H. Precision</td>
<td>0.056m</td>
</tr>
<tr>
<td>V. Precision</td>
<td>0.236m</td>
</tr>
</tbody>
</table>

### Point Derivations

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>B7</td>
</tr>
<tr>
<td>RMS</td>
<td>0.002m</td>
</tr>
<tr>
<td>H. Precision</td>
<td>0.021m</td>
</tr>
<tr>
<td>V. Precision</td>
<td>0.047m</td>
</tr>
</tbody>
</table>
Examples

Introduction to RTQC

- CRC for Spatial Information Project 1.2, 1.12
  - Quality Control Issues for Real Time Positioning
- Provide quality indicators (in real time) that are
  - Reliable
  - Reflect that Mobile Users rely on their own and CORS data
- RTQC (Real-Time Quality Control)
  - Independently assesses quality of positioning in real-time
  - Uses raw measurement data (free from manufacturer algorithms)
  - Integrates CORS Network and Mobile User quality data
Part II

Testing (RTQC Mobile & Quality Indicators)
RTQC Mobile

- Designed to use open standards
  - RTCM 3.x via NTRIP
- Some receivers unable to transmit RTCM in “rover” mode
  - Proprietary formats to overcome this problem
- Quality Information provided to Mobile Users via RTCM
  - RTCM Message 4082
  - Licensed to CRC-SI
  - Open (ask us about it)
RTQC Mobile (Data Formats)

- Proprietary formats in red are currently supported by RTQC

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Format</th>
<th>RTCM3 from Rover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trimble</td>
<td>RT17/RT27, CMR/CMR+/CMRx</td>
<td>✗</td>
</tr>
<tr>
<td>Leica</td>
<td>LB2, 4G</td>
<td>✗</td>
</tr>
<tr>
<td>Novatel</td>
<td>RANGE</td>
<td>✗</td>
</tr>
<tr>
<td>Topcon</td>
<td>TPS</td>
<td>✓</td>
</tr>
<tr>
<td>Javad</td>
<td>JPS</td>
<td>✓</td>
</tr>
<tr>
<td>Ashtech</td>
<td>MBEN/PBEN, DBEN, ATOM</td>
<td>✗</td>
</tr>
<tr>
<td>Sokkia</td>
<td>RANGE</td>
<td>✗</td>
</tr>
</tbody>
</table>
RTQC Mobile (Testing – Sydney Train Survey)

- RTQC system was given its first test on a kinematic railway survey in Sydney
- 2 receivers were configured to stream data to RTQC and receive quality information during a 25km railway survey

Sydney Train Survey Route
RTQC Quality Assessment

- RTQC provides several stages of quality assessment
- Sydney Train Survey examined two of these:
  1. Individual Quality Indicators
  2. Integrated Quality Indicators

RTQC Individual Quality Indicators

- Individual quality indicators ($q$) are formed for each satellite-receiver combination.
- $q$ is derived from raw measurements and is indicative of the level of noise present in the observations.
Individual Quality Indicator (An Example)

- Confirmed basic properties of individual indicators
  - Indicative of the level of noise in the observation data
RTQC Testing – Results (Individual Indicators)

- Confirmed basic properties of individual indicators
  - Indicative of the level of noise in the observation data
- Analysis of outliers in individual indicators
  - Ground truth data (rail line) only decimeter level
  - Unable to compare quality indicators to coordinate deviations.
- Examined individual indicators prior to loss of initialisation
  - 50% more outliers in the lead up to loss of initialisation (compared to normal epochs)
  - Not as discriminating as we thought it would be
  - Why?
RTQC Quality Assessment

- RTQC provides several stages of quality assessment
- Sydney Train Survey examined two of these:
  1. Individual Quality Indicators
  2. Integrated Quality Indicators
Integrated Quality Indicator

- Individual indicators \((q)\) are aggregated to form a single receiver-based indicator \((w)\)

- \(w\) is formed using the following equation:

\[
  w = \frac{1}{n} \sum_{i=1}^{n} \frac{(q_i - \bar{q}_i)}{\sigma_q}
\]

- \(w\) is formed for each CORS and Mobile receiver

Integrated Quality Indicator

- CORS and Mobile Indicators are combined to form an Integrated Indicator \((w_{int})\)

\[
  w_{cors} = \frac{1}{\sum \alpha_j} \sum \alpha_j w_i
\]

\[
  w_{int} = 0.75 w_{cors} + 0.25 w_{mob}
\]

\[
  \alpha_i = \frac{1}{d_i}
\]
RTQC Testing – Results (Integrated Indicators)

- Analysis of outliers in integrated indicators
  - Ground truth data (rail line) only decimeter level
  - Unable to compare quality indicators to coordinate deviations.
- Examined L1 residuals from LGO PPK Solution
  - Problematic, only small patches of fixed L1 solutions
  - 10 outliers detected via integrated indicator
  - 8 (80%) corresponded to significant L1 residuals
  - Promising, but inconclusive (not enough test results)
RTQC Testing Results – Summary

- RTQC Quality Indicators – Successful
  - Hampered by lack of accurate ground truth data
  - Confirmed basic properties of RTQC Quality Indicators
  - Encouraging results for both individual and integrated indicators
  - Improved testing and additional analysis required
- RTQC Mobile – Very Successful
  - No major communications issues or other problems
    - Network RTK (UNSW)
    - RTQC (Melb Uni)
    - 2-Way Mobile Internet (Telstra NextG)

Part III

Quality Indicators and Stochastic Modelling
The Stochastic Model

- GNSS processing is based around least squares (LSQ)
  \[(A^T \Sigma^{-1} A)^{-1} A^T \Sigma^{-1} m,\]
- LSQ requires (as a minimum)
  - Observations
  - Stochastic Model
  - Functional model
  - Unknown Parameters
- Stochastic Model
  - describes the noise present in the observations
  - represented by a Variance Covariance (VCV) Matrix

Why is the Stochastic Model important?

- A correctly defined stochastic model
  - correctly “weights” the GNSS observations in the LSQ algorithm
  - aids the ambiguity resolution process
  - can improve coordinate estimates
  - can improve the reliability of coordinate precision estimates
Stochastic Modelling

- Stochastic Models used in practice include:
  - Elevation Dependent Model
  - SNR (or C/N0) Models (various)
- Only provide variance terms in the VCV Matrix
- Ignore covariances (correlations) between observations
- Three types of physical correlations exist
  - spatial correlations (between satellites)
  - temporal correlations (between epochs)
  - inter-frequency correlations (between frequencies)

Variance-Covariance Matrix

The matrix shows the variance-covariance between different epochs and frequencies.
Quality Indicators & Stochastic Modelling

- RTQC Individual Quality Indicators
  - Calculated directly from observation data (simple process)
  - Indicative of noise in the observations
- Compute variances directly from quality indicators
- Compute covariances directly from quality indicators
- Examine covariances for evidence of correlation

Stochastic Modelling – Spatial Correlations
Future Work

- **Quality Indicators**
  - Improve testing and analysis

- **Stochastic Modeling**
  - Investigation of temporal and inter-frequency correlations
  - Rigorous testing of the model

- **Recent advance (last week)**
  - Incorporation of Reverse RTK into RTQC to facilitate the rigorous testing of the stochastic model
  - Yong Heo (UNSW)

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Cody Corporation – Luke Fulton, Bryan Robinson
GlobalPos – Brad Stephenson
Lightwave Technology – Justin Davies
Ultimate Positioning – Paul Standen, Paul Andrews
RTQC – It will keep you out of trouble!