On the Robustness of Next Generation Phase-only Real-Time Kinematic Positioning

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Motivation

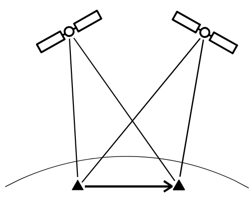
- Code observations more affected by multipath than phase observations
- Curiosity: Robustness and possibility next generation GNSS phase-only RTK

Contents

- Real-Time Kinematic Positioning
- Phase-only versus Code and Phase
- Phase-only RTK design computations
- Phase-only RTK experimental results
- Conclusions

Real-Time Kinematic Positioning

- Relative positioning
- Epoch-by-epoch solution
- Consider short baseline neglecting atmosphere



Resolving of double-differenced integer phase-ambiguities is the key to precise GNSS RTK positioning

Integer Least Squares strategy

1. Standard LS adjustment gives real-valued float estimates for unknown (integer) ambiguity and baseline parameters

   (i) $\begin{bmatrix} \hat{a} \\ \hat{b} \end{bmatrix} , \begin{bmatrix} Q_{\hat{a}\hat{a}} & Q_{\hat{a}\hat{b}} \\ Q_{\hat{b}\hat{a}} & Q_{\hat{b}\hat{b}} \end{bmatrix}$

2. Resolve integer LS estimate for ambiguity parameters

   (ii) $\check{a} = \arg\min_{a \in Z^n} \| \hat{a} - a \|^2_{Q_{\hat{a}\hat{a}}}$

3. Correct float baseline parameter to obtain fixed baseline solution

   (iii) $\check{b} = \hat{b} - Q_{\hat{b}\hat{a}} Q_{\hat{a}\hat{a}}^{-1} (\hat{a} - \check{a})$

Phase-only ← → Code and phase

- Code and phase RTK model

$$
\begin{aligned}
p_j(i) &= + G(i)b \\
\phi_j(i) &= \lambda_j a_j + G(i)b
\end{aligned}
$$

Phase-only ← → Code and phase

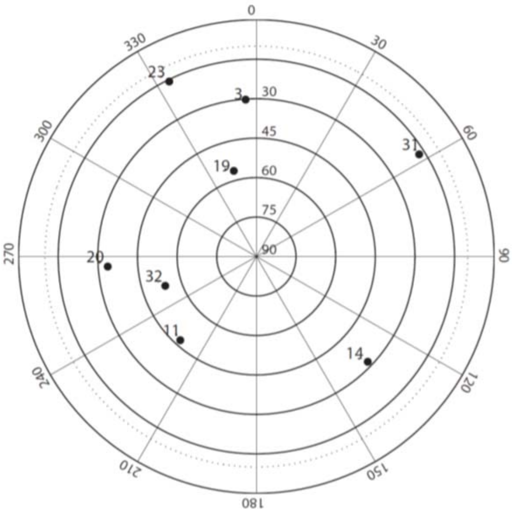
- Phase-only RTK model

$$\phi_j(i) = \lambda_j a_j \quad + \quad G(i)b$$

Phase-only design computations

- Measure for performance: Bootstrapped ambiguity success-rate

Phase-only design computations



- 8 satellites
- Elevation dependent weighting

$$\sigma_{\phi_i}^{s} = \sigma_{\phi_i}(1+10\exp\{-\frac{\theta^{s}}{10^{\circ}}\})$$

- Data rate 1Hz
- GPS L1/L2/L5 phase-observations

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GPS L1/L2/L5 phase-observations

Frequencies	Success-rate 4 satellites	Success-rate 5 satellites	Success-rate 6 satellites	Success-rate 7 satellites	Success-rate 8 satellites
$L1$	0.0000	0.0000	0.0002	0.0036	0.1602
$L1/L2$	0.2159	0.7564	0.9993	1.0000	1.0000
$L1/L5$	0.2500	0.8382	0.9999	1.0000	1.0000
$L2/L5$	0.1554	0.9227	1.0000	1.0000	1.0000
$L1/L2/L5$	0.9850	1.0000	1.0000	1.0000	1.0000

The phase-only dual-epoch success-rate for different frequencies with 1 second time interval and σ_{ϕ_i} = 1 mm

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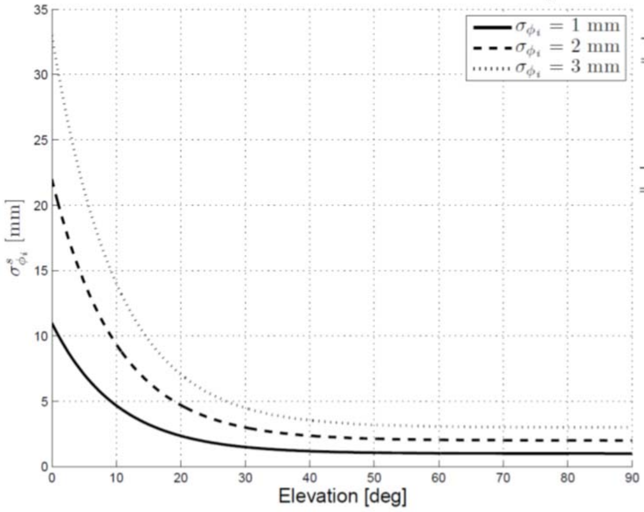
Measurement precision



σ_{ϕ_i} [mm]	Success-rate with 6 satellites
1	0.9993
2	0.6976
3	0.1878

σ_{ϕ_i} [mm]	Success-rate with 7 satellites
1	1.0000
2	0.9649
3	0.5940

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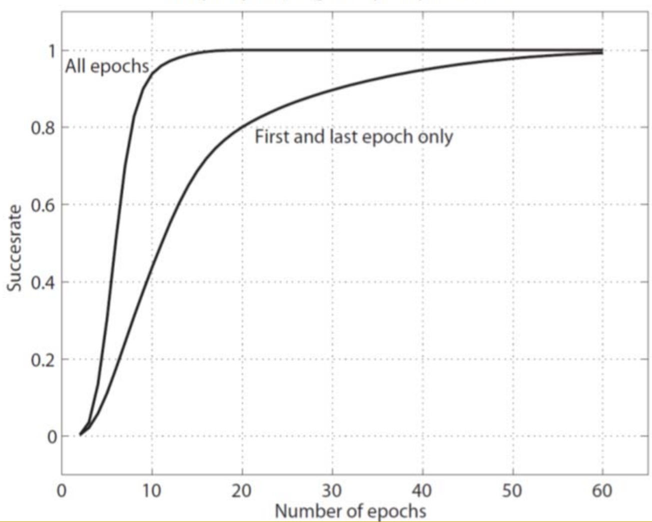
Phase-only Single Frequency GPS

Multiple epoch, single frequency succesrates



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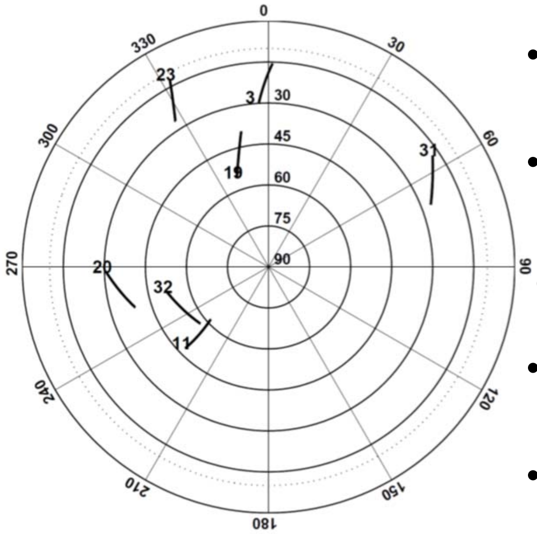
Phase-only experimental results



- 7 satellites
- Elevation dependent weighting

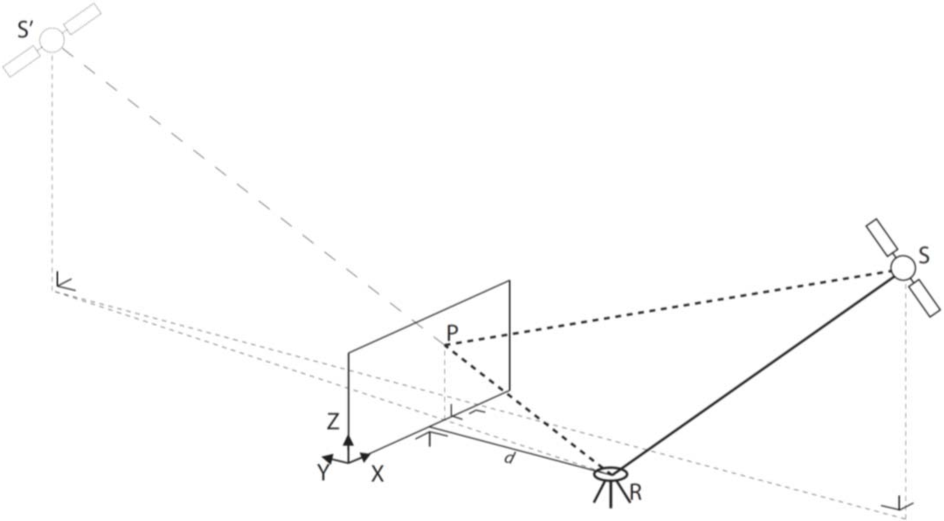
$$\sigma_{\phi_i}^{s} = 0.001*(1+10\exp\{-\frac{\varepsilon^{s}}{10^{\circ}}\})$$

- Data rate 1Hz
- GPS L1/L2 code and phase- observations

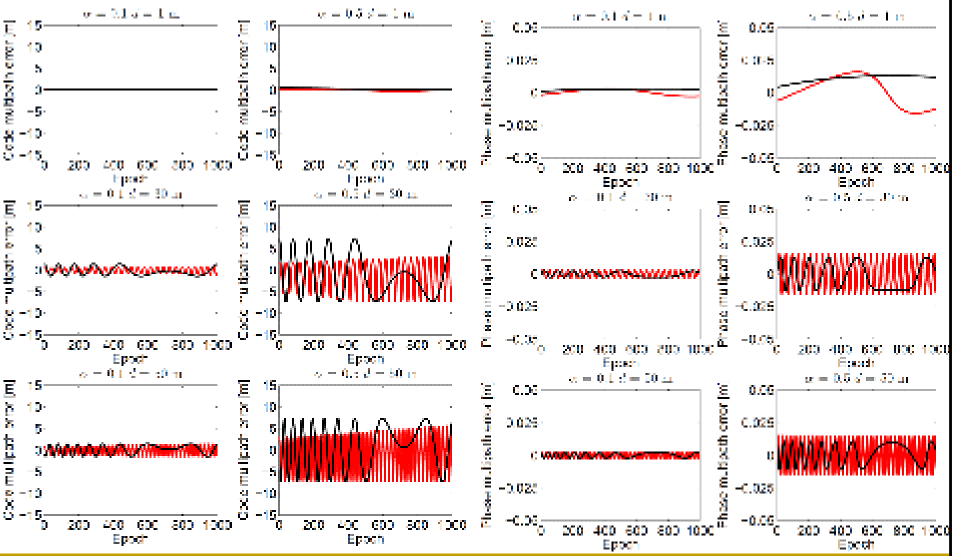
Robustness - Introducing multipath

- Introduce vertical reflecting surface
- Vary
  - distances to the receiver of the vertical reflecting surface
  - attenuation of the reflected signal with respect to the direct signal

Introducing multipath



C/A and L1 multipath error for PRN3 and PRN31



Empirical phase-only success-rates

α	$d[m]$	*observables* $L1/L2$	*observables* $C\backslash A/L1/P2/L2$
0.1	1	0.998	0.885
	30	0.998	0.552
	50	0.998	0.524
0.5	1	0.683	0.489
	30	0.811	0.552
	50	0.846	0.528

Ratio of correctly fixed coordinates provided the ambiguities were fixed correctly

α	$d[m]$	*observables* $L1/L2$	*observables* $C\backslash A/L1/P2/L2$
0.1	1	0.998 1.000	0.885 0.000
	30	0.998 1.000	0.552 0.103
	50	0.998 1.000	0.524 0.095
0.5	1	0.683 0.991	0.489 0.000
	30	0.811 0.995	0.552 0.111
	50	0.846 0.998	0.528 0.129

Empirical success rate (1000 samples)

Number of epochs with correct baseline coordinates

Number of epochs with correct ambiguities

Ratio of correctly fixed coordinates provided the ambiguities were fixed correctly

α	$d[m]$	observables $L1/L2$	observables $C\backslash A/L1/P2/L2$
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$$\breve{b} = \hat{b} - Q_{\hat{b}\hat{a}} Q_{\hat{a}\hat{a}}^{-1} (\hat{a} - \breve{a})$$

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Conclusions

- Epoch-by-epoch phase-only RTK possible with dual and triple frequency GNSS when respectively 6 and 5 satellites are tracked
- The phase-only RTK model is more robust against multipath than the code and phase RTK model

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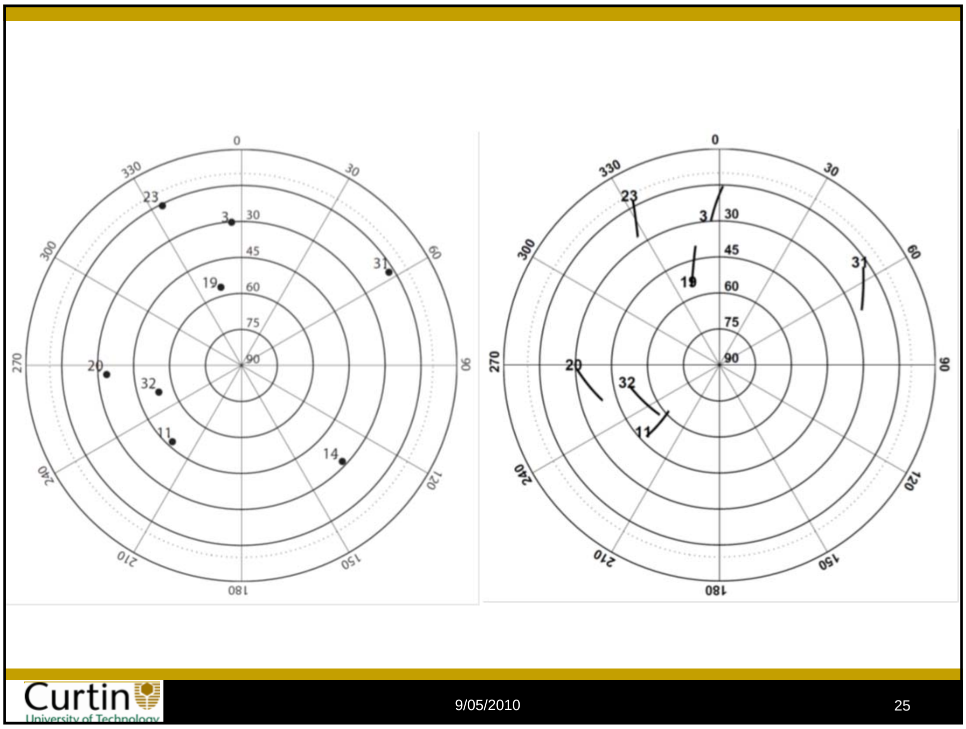

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