MEMS-based IMU Assisted Real Time Difference Using Raw Measurements from Smartphone

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1 Introduction & Motivation

2 RTD+IMU Positioning Algorithm

3 Experiment Architecture

4 Result and Analysis

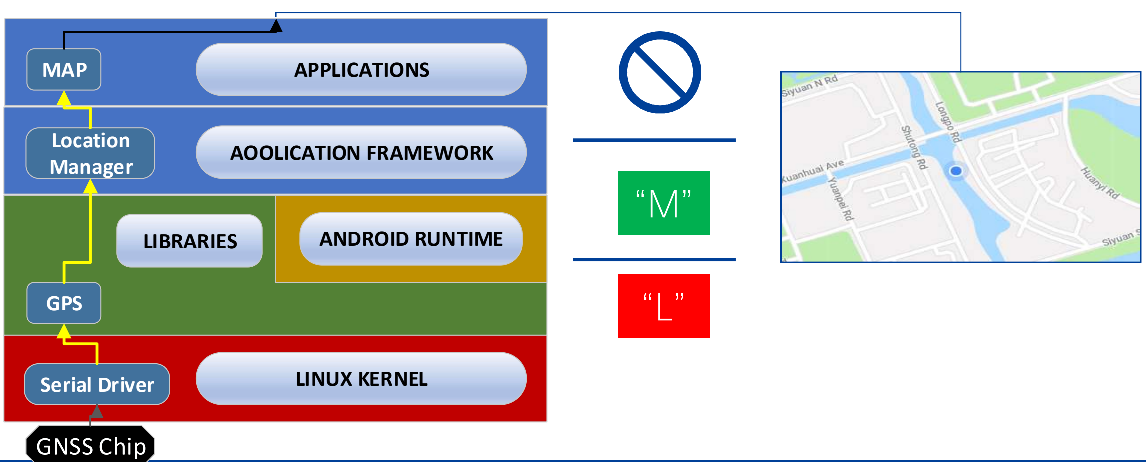
5 Conclusion & Future Works

Introduction & Motivation

- Low cost tendency for high precision positioning




- GNSS raw measurement unavailable



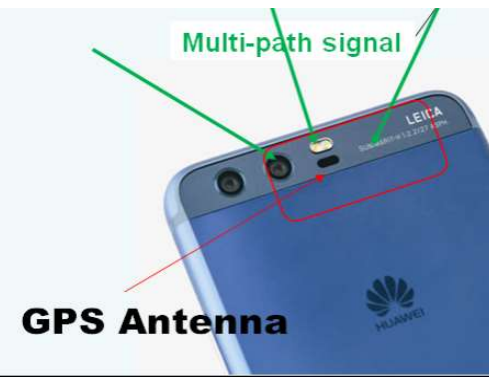
ANDROID
NOUGAT

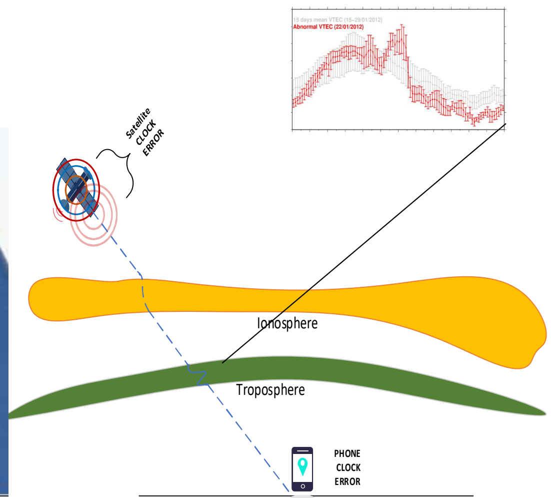
GnssMeasurement

GnssClock

Introduction & Motivation

- Complex noise sources





- IMU Auxiliary

Rotation matrix

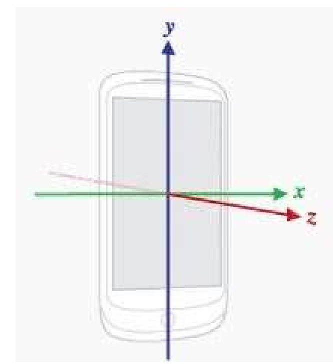
↓

`getRotationMatrixFromVector`

`TYPE_LINEAR_ACCELERATION`

↑

Acceleration in body-frame



IMU enable to offer high accurate rotate and accelerate information

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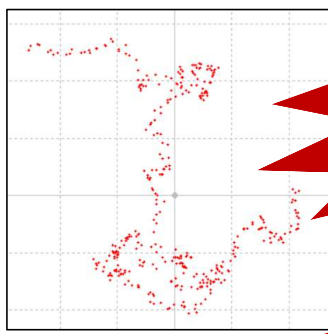
RTD+IMU Positioning Algorithm

- Traditional Pseudorange single point

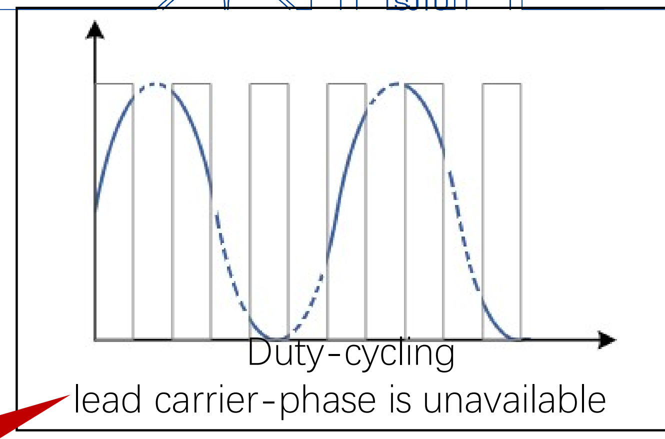
$$\rho^{(n)} = r^{(n)} + \delta t_u - \delta t^{(n)} + I^{(n)} + T^{(n)} + \xi_{\rho}^{(n)}$$

Nonlinear **Least Square**



Multiple iterations

Not smooth



RTD+IMU Positioning Algorithm

- Kalman Filter

$$\rho_u^{(n)} = r_u^{(n)} + \delta t_u - \delta t^{(n)} + I_u^{(n)} + T_u^{(n)} + \xi_{\rho u}^{(n)}$$

$$\dot{\rho}_u - \mathrm{v}^{(n)} \cdot I_u + \delta f^{(n)} - \zeta \rho_u = -\mathrm{v}_u \cdot I_u + \delta f_u$$

Prediction

Updating

- Doppler measurement accuracy is **one hundred times** the pseudorange accuracy
- Ionosphere and troposphere errors can result **dozens of meters**, difference or dual frequency correction is common method to eliminate these errors.
- Rover baseline direction vector I_u stability is unreliable.

RTD+IMU Positioning Algorithm

- Difference Kalman Filter——Doppler

subtraction

$$\dot{\rho}_u - v^{(n)} \cdot I_u + \delta f^{(n)} - \zeta \rho_u = -v_u \cdot I_u + \delta f_u$$

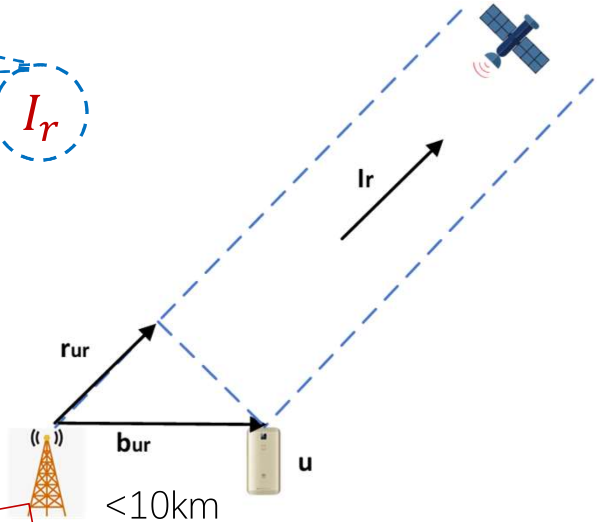
$$-$$

$$\dot{\rho}_r - v^{(n)} \cdot I_r + \delta f^{(n)} - \zeta \rho_r = -v_r \cdot I_r + \delta f_r$$

$$\dot{\rho}_{ur}^{(n)} = -v_r \cdot I_r + c\delta f_{ur}$$

I_r

Common mode errors are calculated together



Short baseline hypothesis

RTD+IMU Positioning Algorithm

- Difference Kalman Filter——Pseudorange

subtraction

$$\rho_u^{(n)} = r_u^{(n)} + \delta t_u - \delta t^{(n)} + I_u^{(n)} + T_u^{(n)} + \xi_{\rho u}^{(n)}$$

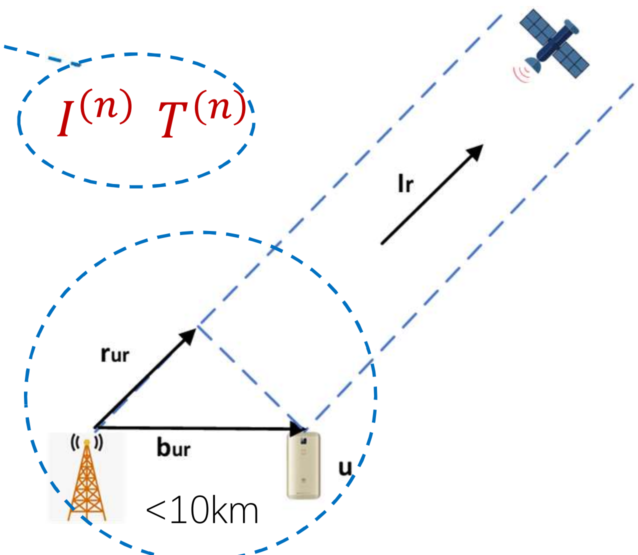
$$-$$

$$\rho_r^{(n)} = r_r^{(n)} + \delta t_r - \delta t^{(n)} + I_r^{(n)} + T_r^{(n)} + \xi_{\rho r}^{(n)}$$

$$\rho_{ur}^{(n)} = r_{ur}^{(n)} + c\delta t_{ur}$$

$$r_{ur}^{(n)} = -b_{ur} \cdot I_r$$

$$\rho_{ur}^{(n)} = -b_{ur} \cdot I_r + c\delta t_{ur}$$



Short baseline hypothesis

Linearized the observation vector, extend kalman filter is no more needed.

RTD+IMU Positioning Algorithm

- Difference Kalman Filter——IMU

$$a_{enu} = R \times a_{body}$$

$$\hat{a}_k = a_{\overline{k-1}} + \delta a_{\overline{k-1}}$$

- **High update frequency**
- **High instantaneous accuracy**

RTD+IMU Positioning Algorithm

- Double Difference Kalman Filter

$$\rho_{ur}^{(i)} = -b_{ur} \cdot I_r^{(i)} + c\delta t_{ur}$$

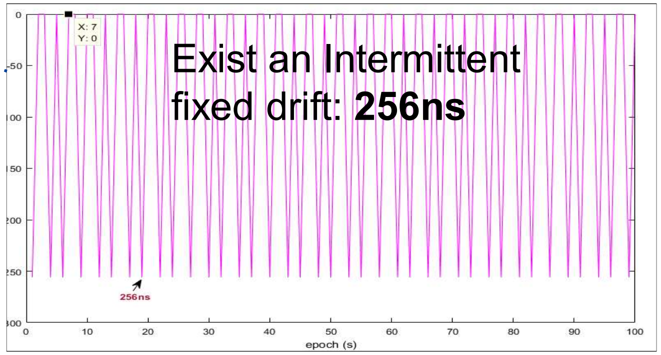
subtraction

$$\rho_{ur}^{(j)} = -b_{ur} \cdot I_r^{(j)} + c\delta t_{ur}$$

J = max Angle satellite

$$\rho_{ur}^{(ij)} = -b_{ur} \cdot (I_r^{(i)} - I_r^{(j)})$$

$$\dot{\rho}_{ur}^{(ij)} = -v_r \cdot (I_r^{(i)} - I_r^{(j)})$$



Gnss clock drift

$$\begin{bmatrix} \mathbf{R}_{sat} \\ \mathbf{R}_{a} \end{bmatrix} = \begin{bmatrix} \mathbf{C}^2 \cdot \mathbf{10}^{-\mathbf{CNR}^{(i)}/10} & & & \\ & R_{ax} & & \\ & & R_{ay} & \\ & & & R_{az} \end{bmatrix}$$

CNR or Satellite angle are equivalent

RTD+IMU Positioning Algorithm

- Difference Kalman Filter——Updating matrix

$$\begin{bmatrix} b_{ur} \\ v \\ a \\ \delta a \end{bmatrix} = \begin{bmatrix} 1 & T_S & \frac{T_S^2}{2} & 0 \\ 0 & 1 & T_S & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} b_{ur} \\ v \\ a \\ \delta a \end{bmatrix}$$

$$P_{\bar{k}} = A_c P_{k-1} A^T + Q$$

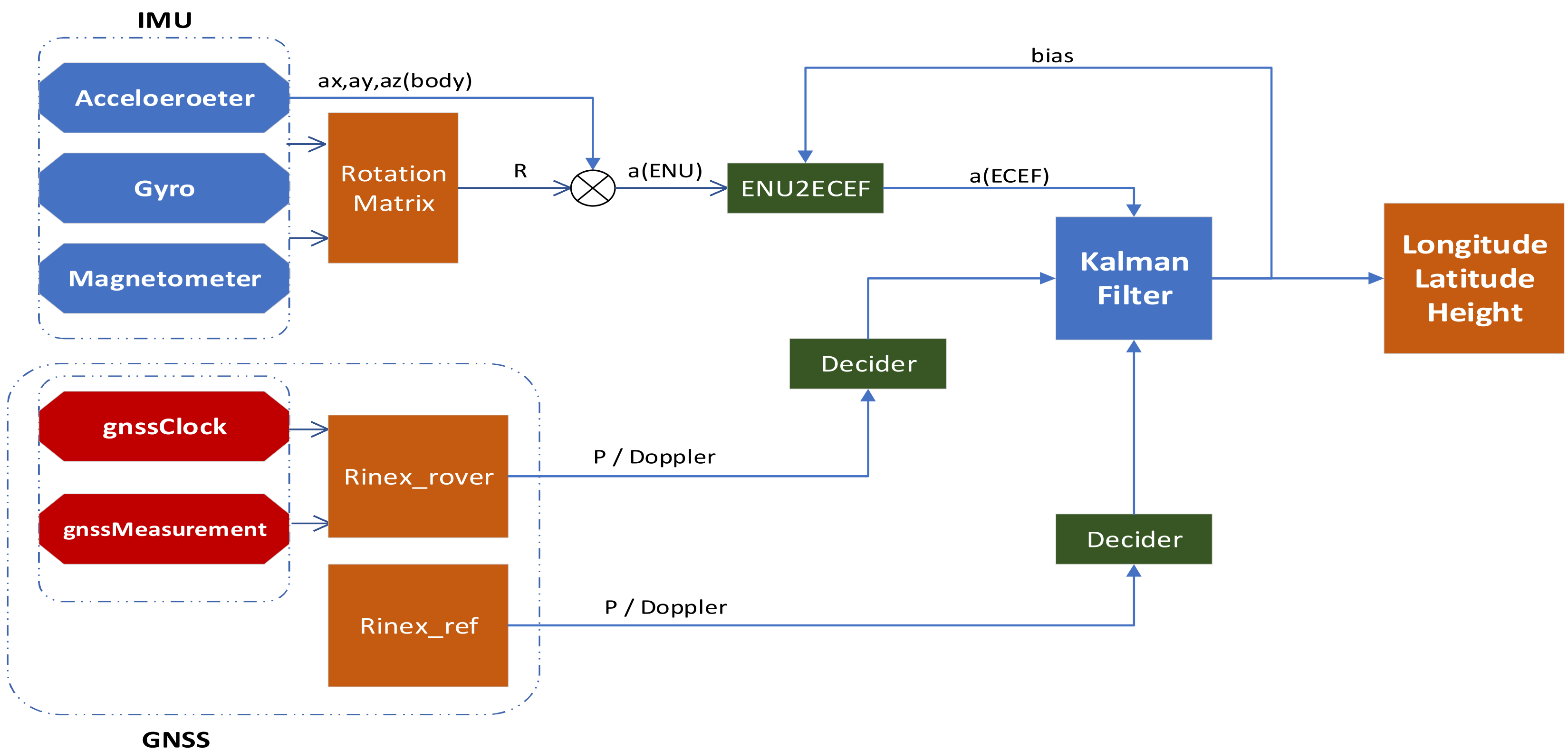
$$\mathbf{Q} = \begin{bmatrix} Q_p & 0 \\ 0 & Q_a \end{bmatrix}$$

Assuming that the noises are independent of each other, the autocorrelation function with impulse response

$$\mathbf{Q_p} = \begin{bmatrix} S_x T_S + S_v \frac{T_S^3}{3} + S_a \frac{T_S^5}{20} & S_v \frac{T_S^2}{2} + S_a \frac{T_S^4}{8} & S_a \frac{T_S^3}{6} \\ S_v \frac{T_S^2}{2} + S_a \frac{T_S^4}{8} & S_v T_S + S_a \frac{T_S^3}{3} & S_a \frac{T_S^2}{2} \\ S_v \frac{T_S^3}{6} & S_v \frac{T_S^2}{2} & S_a T_S \end{bmatrix}$$

RTD+IMU Positioning Algorithm

- System Framework



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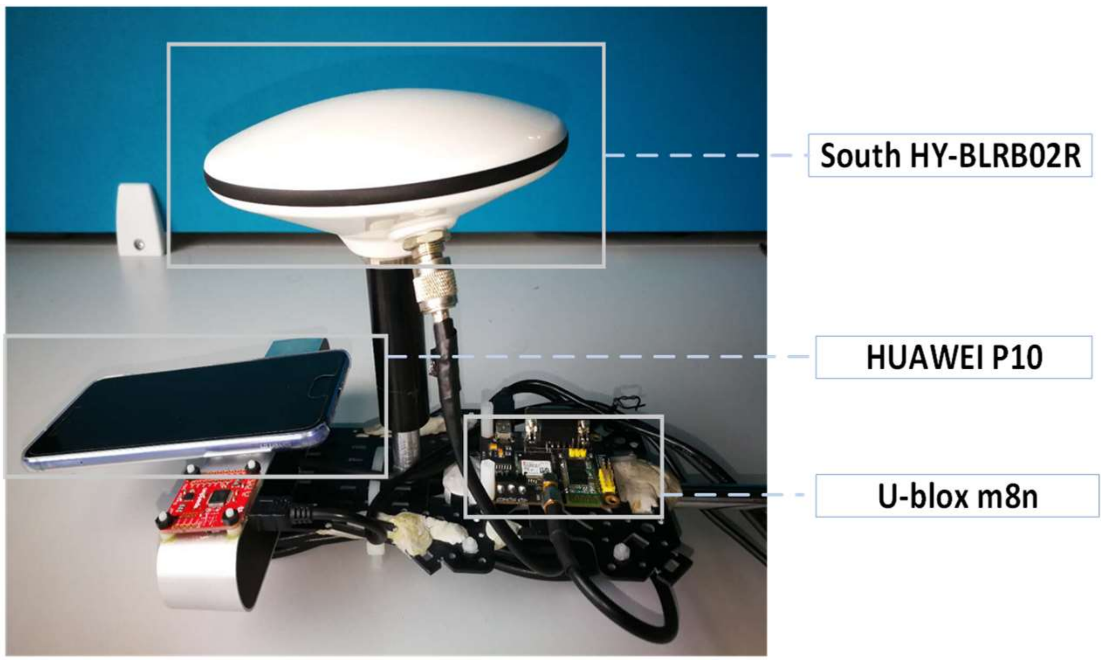
Experiment Architecture

- System setup

Handheld platform



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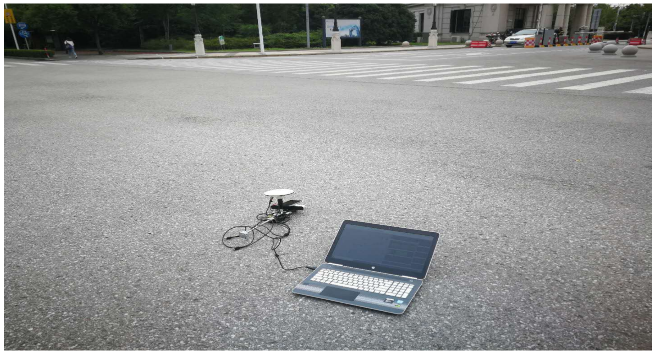
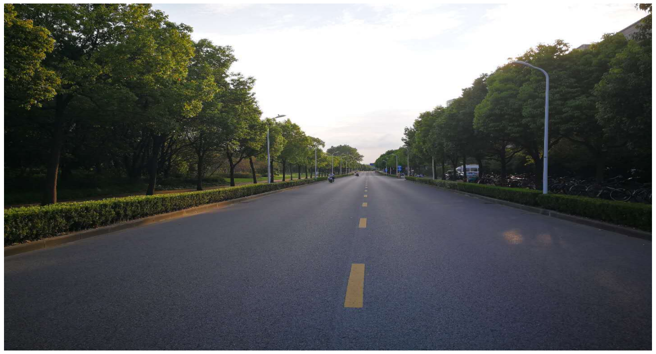
Experiment Architecture

- Experiment environment

Static





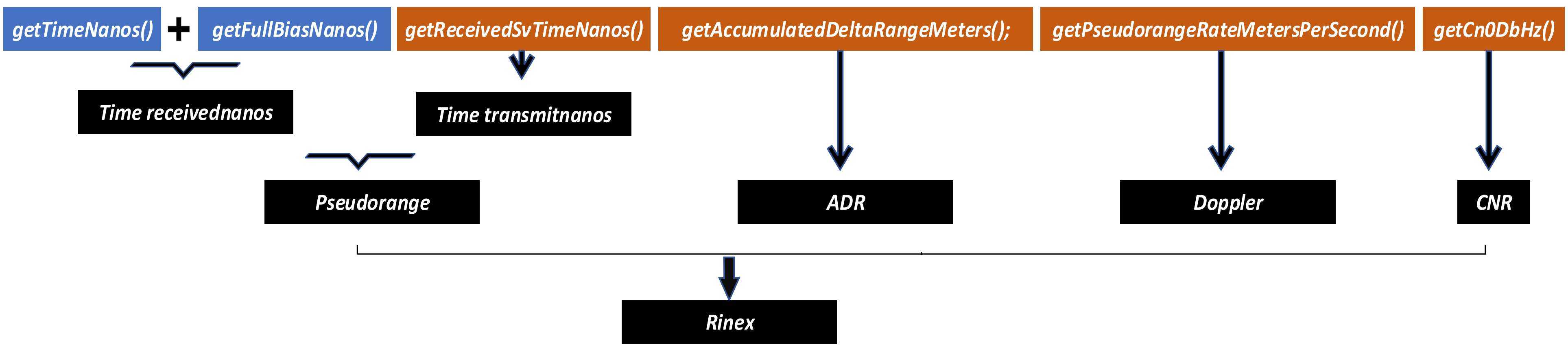
Kinematic

Blockage

Blockage

Experiment Architecture

- RINEX generation



- **getPseudorangeRateUncertaintyMetersPerSecond() < 10 & getReceivedSvTimeUncertaintyNanos() < 500**
- **Pseudorange value > 1e7 & Pseudorange < 3e7**
- **Satellite angle >15 degree & CNR >15 dB**
- **Max position movement per epoch < 10m**

Threshold

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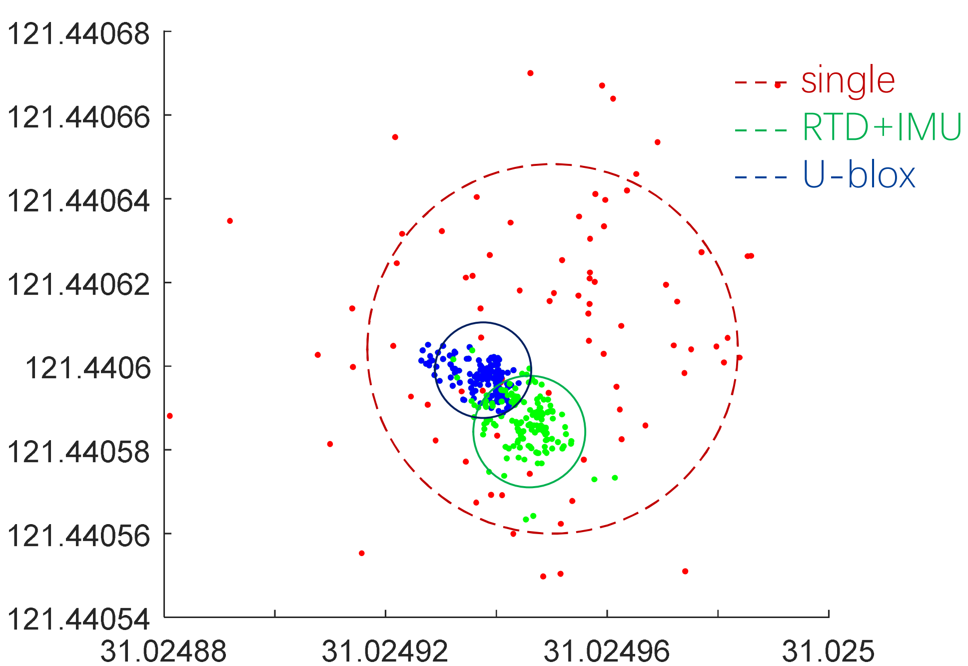
Result and Analysis

- Static

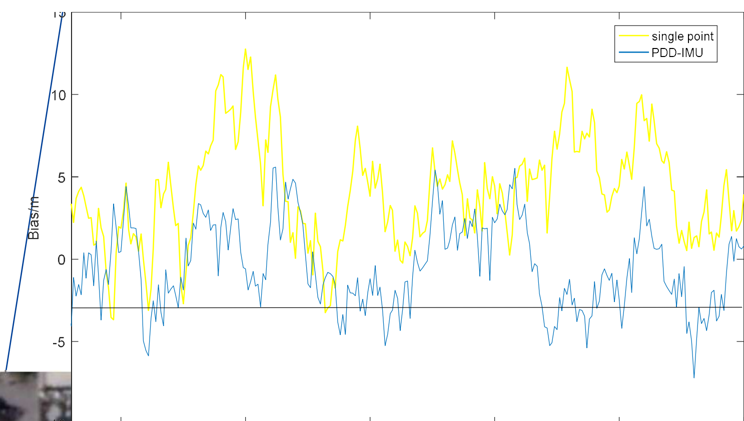


Horizontal error	Mean error (m)	STD (m)
Single point	4.51	9.57
RTD	4.11	3.99
U-blox	3.88	3.74

Result and Analysis

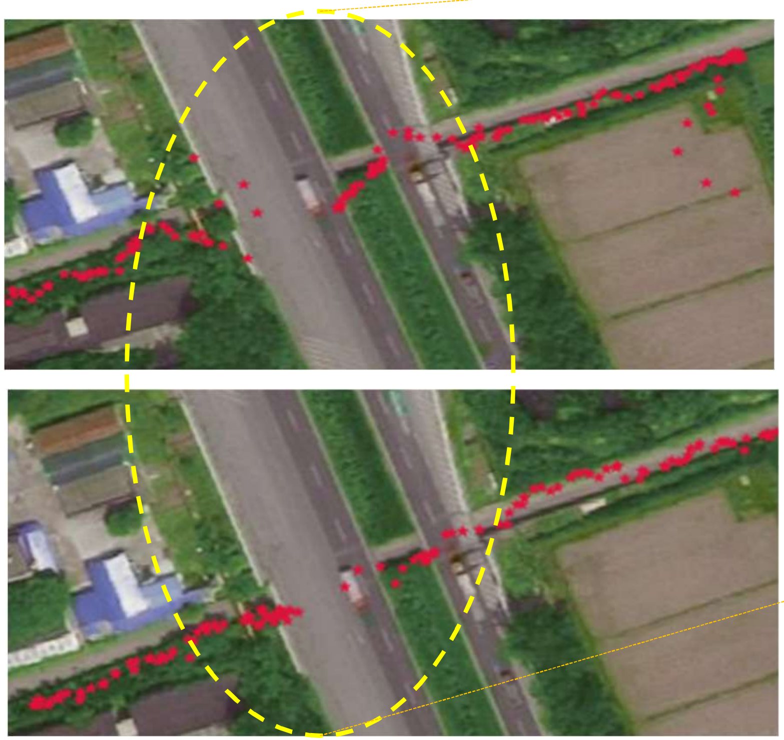
- Kinematic

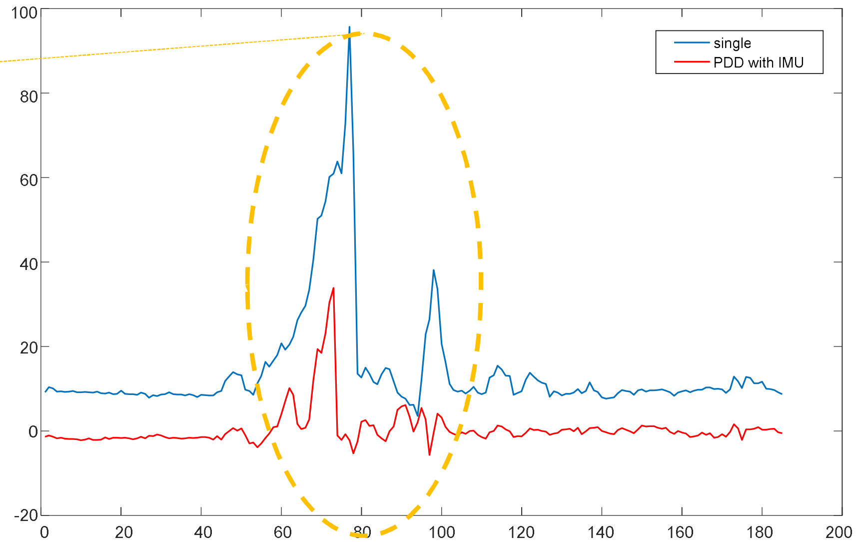
Horizontal error	Mean error (m)	STD (m)
Single point	6.77	5.00
RTD+IMU	3.71	2.60
U-blox m8n	4.60	2.62



Result and Analysis

- Blockage





- **Calibrate the fixed error**
- **Release the drastic drift when GNSS signal blocked**

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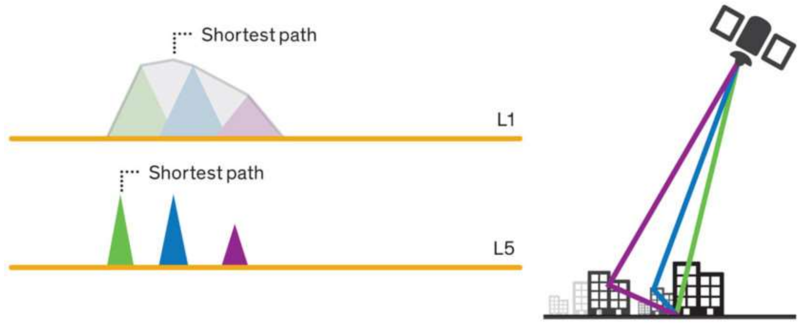
Conclusion & Future Works

- Conclusion
  - PDD model was presented and clarified the advantages than traditional solutions
  - IMU of smartphone enable to assist GNSS performance, but its stability is unreliable.
  - MEMS-based IMU assisted RTD increases smartphone positioning precision and robustness, and the mean accuracy can be less than 3 meters.
- Future Works
  - GNSS new fusion way
  - Multi-frequency.



Thanks

Q&A