Fusion of RTK GNSS receiver and IMU for accurate vehicle tracking

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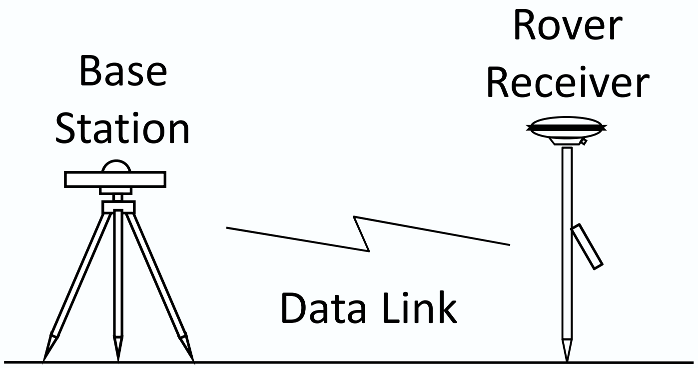
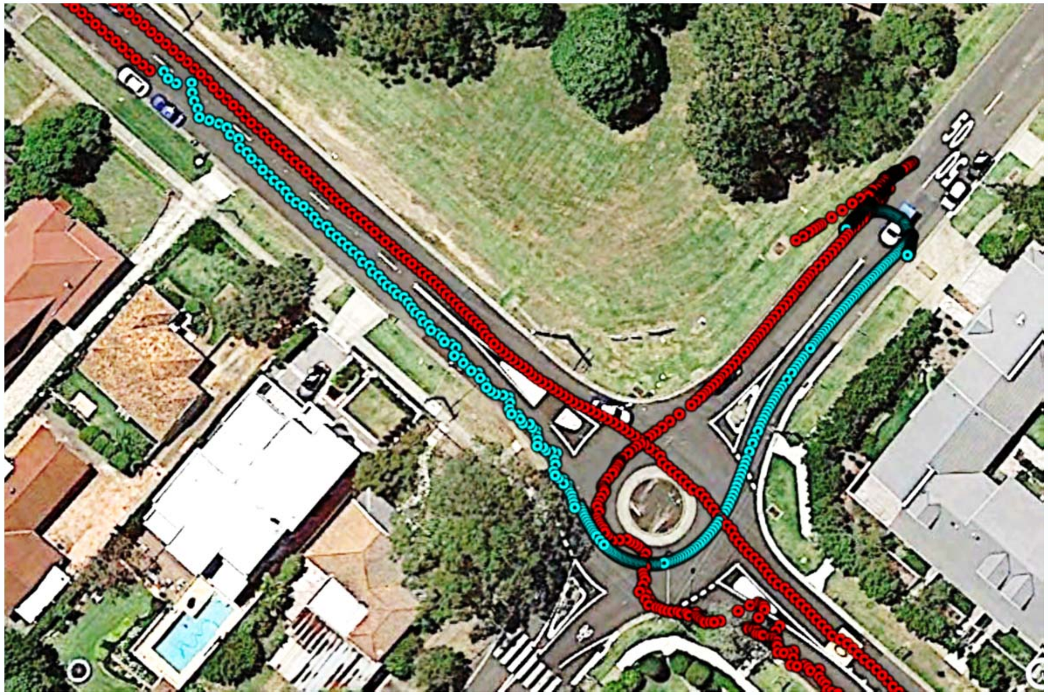
Outline

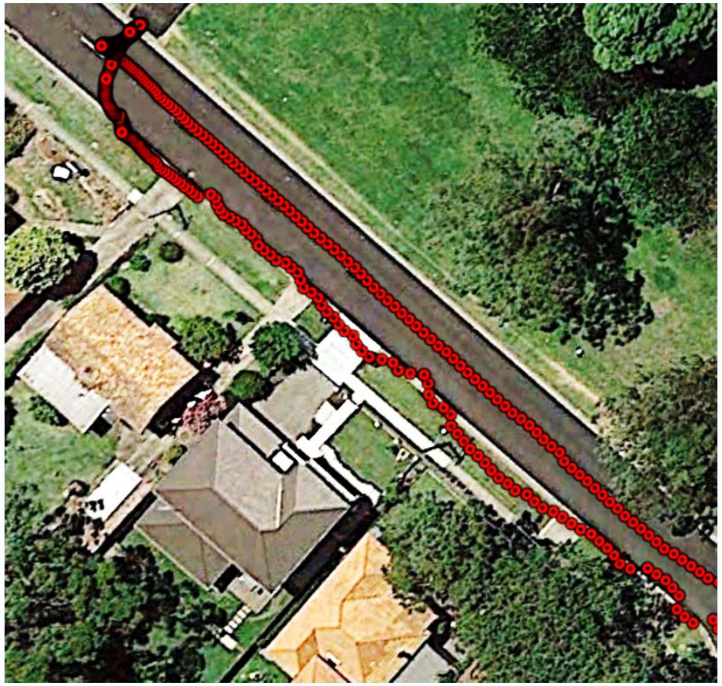
- Backgrounds
  - RTK-GPS
  - IMU-based Sensor Fusion
  - Scenario: unsynchronized GPS and IMU measurements
- Proposed Approach
  - Joint trajectory and clock offset estimation
  - Simplified approach: bisection search over clock offset with conventional Bayesian smoothing-based tracking
- Experimental Results
- Conclusion

Background – RTK GPS

- Carrier phase tracking
- Centimetre-level accuracy in fixed mode
- Key performance indicator: fixing ratio
- Accuracy significantly reduced in floating mode





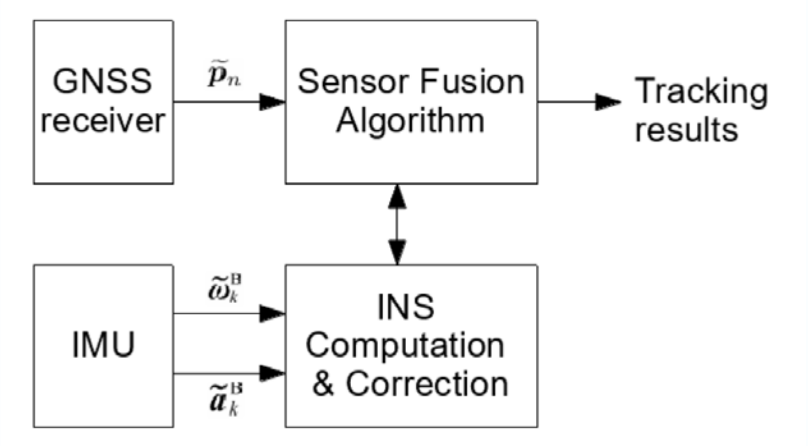


Blue dots: RTK fixed   Red dots: RTK float

Background – IMU-based Sensor Fusion

- ❑ Sensor Fusion in Wireless Positioning Systems
  - IMU measurements complementary to wireless range measurements

- ❑ Advantages
  - Higher Accuracy & Reliability
  - Information on attitude
  - Provide position information during GPS outage (e.g., receiver in tunnels)

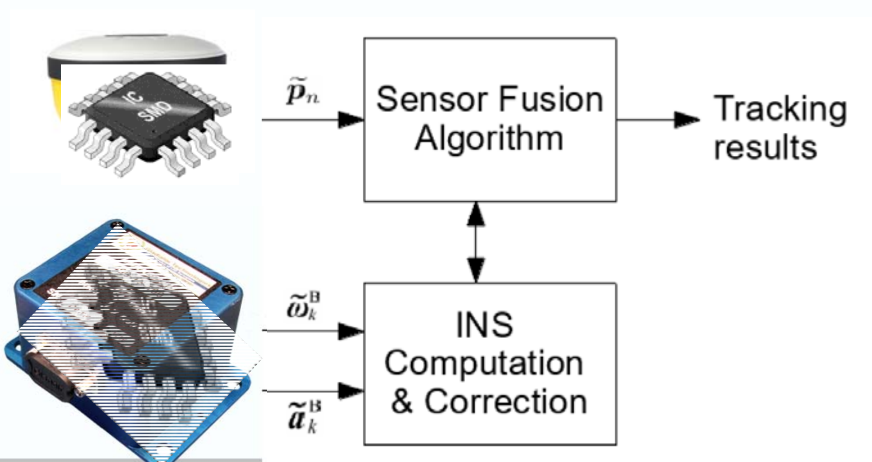


Scenario

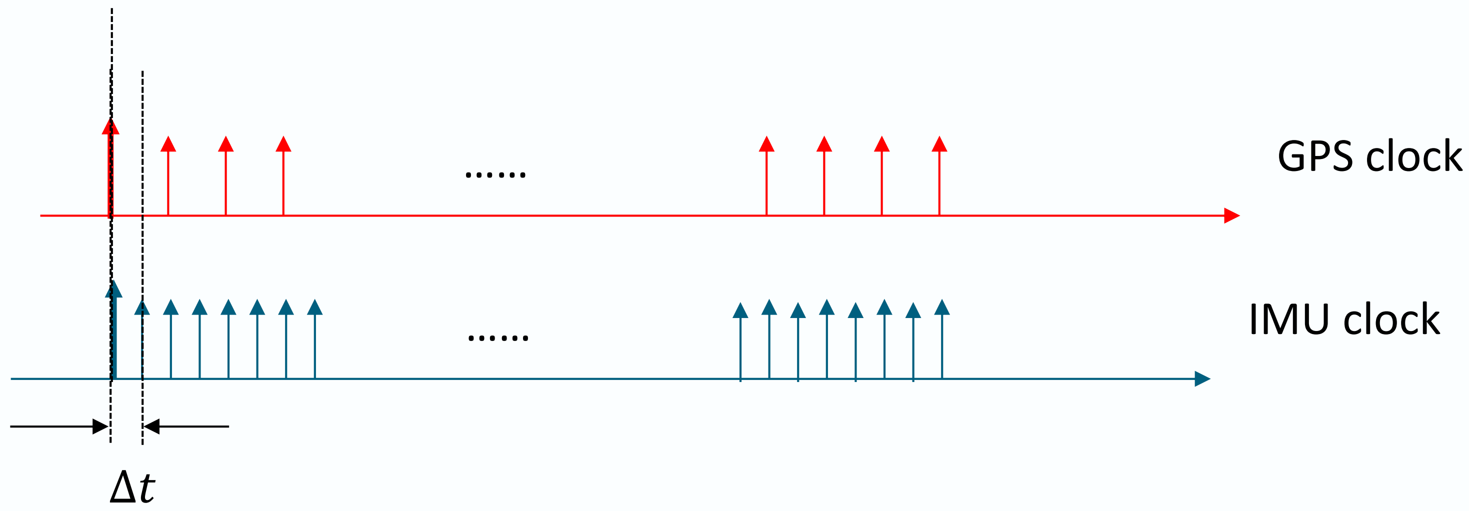
......


Yaw
Roll
Pitch

......


$\tilde{p}_n$
Sensor Fusion Algorithm
Tracking results
$\tilde{\omega}_k^B$
$\tilde{a}_k^B$
INS Computation & Correction

Lack of clock synchronization between GPS receiver and IMU



$$t^{\mathrm{IMU}} = t^{\mathrm{GPS}} - \Delta t$$ (IMU started late)

Impact of clock offset between GPS receiver and IMU

Δt=0.5s

50Km/h

12:00:00.0 @GPS
11:59:59.5 @IMU

12:00:00.5 @GPS
12:00:00.0 @IMU

7m

At IMU time 12:00, using the GPS measured at GPS time 12:00, which in fact is the position measured 0.5s ago.

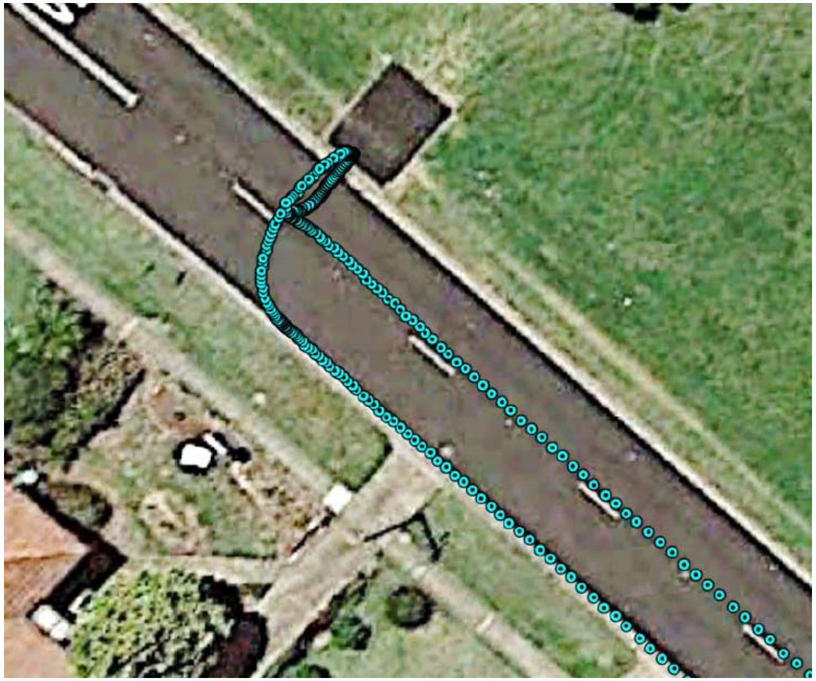
Tracking result without considering the clock offset

GPS

GPS + IMU
(EKF)

Tracking result without considering the clock offset

GPS



GPS + IMU
(EKF)

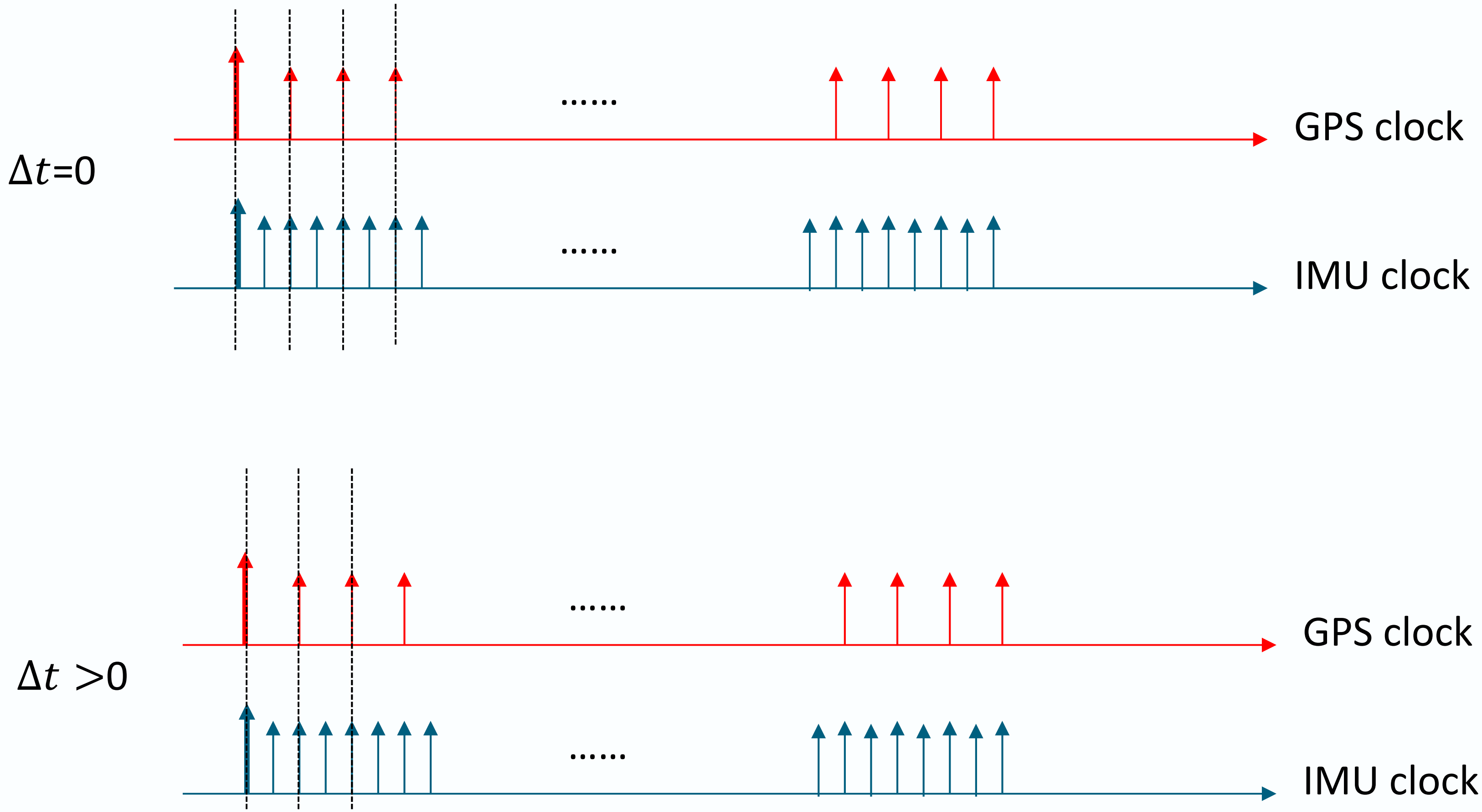
Proposed approach – Estimate the clock offset in the fusion algorithm

- ❑ Problem formulation (Bayesian)

$$p\left(\{\boldsymbol{x}_k\}_{k=0}^{K}, \Delta t \middle| \{\boldsymbol{\omega}_k, \boldsymbol{a}_k\}_{k=1}^{K}, \{\boldsymbol{r}_n\}_{n=1}^{N}\right) = p_0(\boldsymbol{x}_0)p_0(\Delta t)\prod_{k=1}^{K} p(\boldsymbol{x}_k|\boldsymbol{x}_{k-1})\prod_{n=1}^{N} p_{\Delta t}\left(\boldsymbol{r}_n\middle|\boldsymbol{x}_{k_n}\right)$$

- ❑ Extremely hard to solve (linearization in EKF, Monto Carlo method in PF)
- ❑ Reason: Δt controls k_n, the association between GPS and IMU measurements.

The role of Δt



Proposed approach

- For a given Δt
  - Work out the association between GPS and IMU measurements
  - Apply conventional sensor fusion algorithm (Bayesian smooth)

$$\Delta t: \quad \{\boldsymbol{\omega}_k, \boldsymbol{a}_k\}_{k=1}^{K}, \{\boldsymbol{r}_n\}_{n=1}^{N} \quad \Rightarrow \{\boldsymbol{x}_k\}_{k=0}^{K}$$

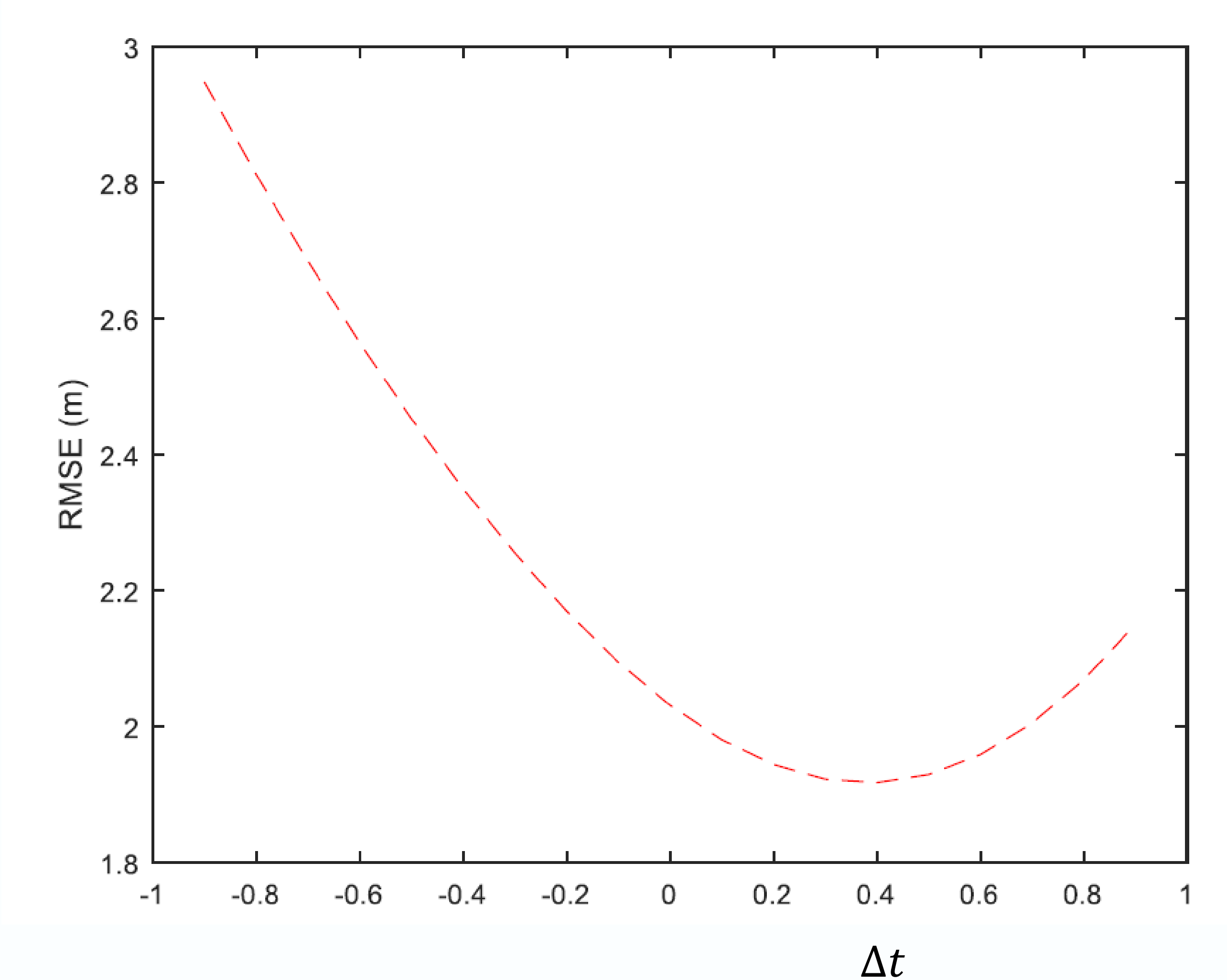
- If Δt is correct, the estimated trajectory $\{\boldsymbol{x}_k\}_{k=0}^{K}$ should be consistent with the GPS measurements $\{\boldsymbol{r}_n\}_{n=1}^{N}$

- Search over Δt, find the clock offset that results in the highest consistency between the estimated trajectory and the GPS measurements (minimum RMSE)
- Since the dimension of Δt is one, the search can be done efficiently using bisection method

Experiments

- GPS and IMU are independently packed modules – no means to drive both devices with one clock
- “Manual synchronization” attempted (press the start buttons for both devices at the same time)

Experiments



Relationship between the RMSE and clock offset

"Manually Synchronized" to 0.4 s!

Results – Example 1 - No clock offset correction

GPS

GPS + IMU
(EKF)

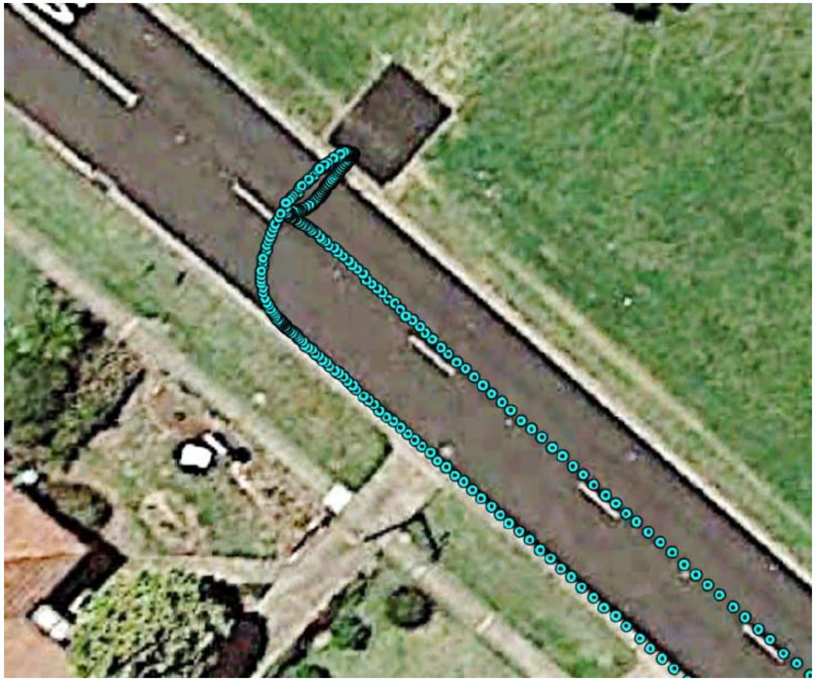
Results – Example 1 – With clock offset correction

GPS

GPS + IMU
(EKF)

Results – Example 2 - No clock offset correction

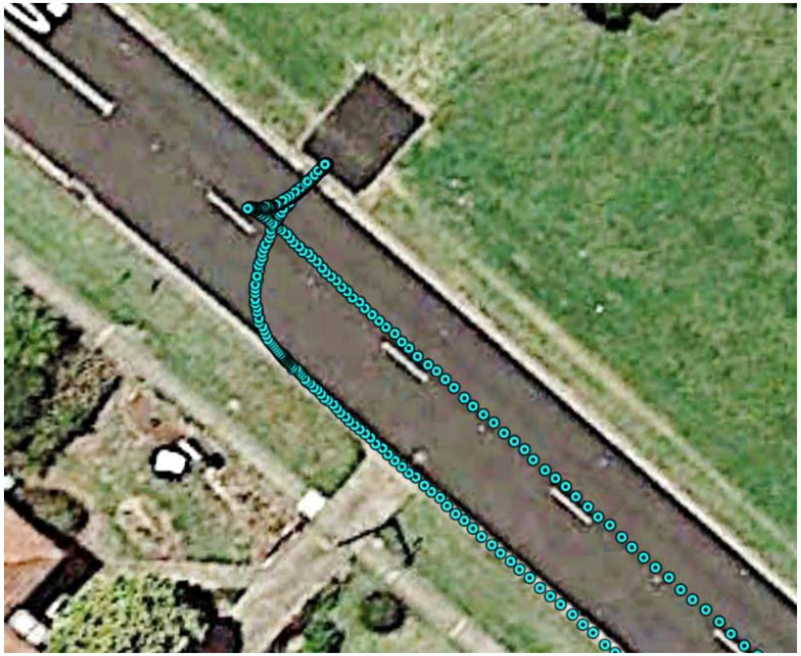
GPS



GPS + IMU
(EKF)

Results – Example 2 – With clock offset correction

GPS



GPS + IMU
(EKF)

Conclusion

- Clock synchronization between GPS and IMU critical for vehicle tracking
- Arrives when developing sensor fusion systems with independently-packed GPS receivers and IMUs
- Include clock offset as a nuisance parameter to be estimated along with the trajectory
- Simplified to bisection search with conventional Bayesian smoothing-based tracking
- With the clock offset worked out, the data can be corrected and used for scientific research or engineering test