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I'm a second-year Master student at Electronic and Telecommunication in Shanghai Jiao Tong University. Previously, I completed my Bachelor degree at Telecommunication in Xidian University, Xi’ an. My interests are multi-sensor fusion navigation, pose estimation and GNSS double difference positioning algorithm based on low-cost devices.

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Pseudorange Double Difference and PDR Fusion Algorithm Using Smartphone GNSS Raw Measurements

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导航，遇见十年
NAVIGATION, 10 YEARS AND BEYOND

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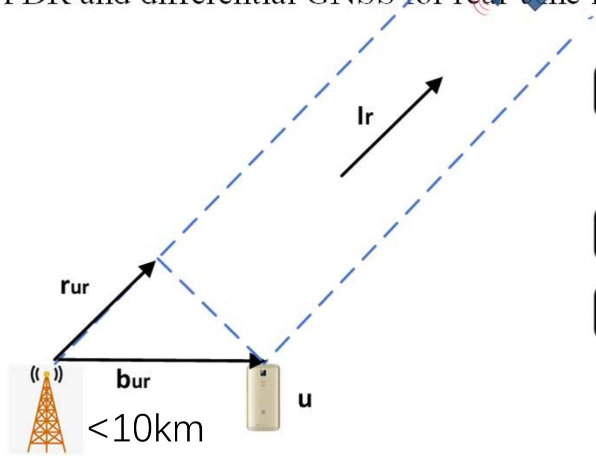
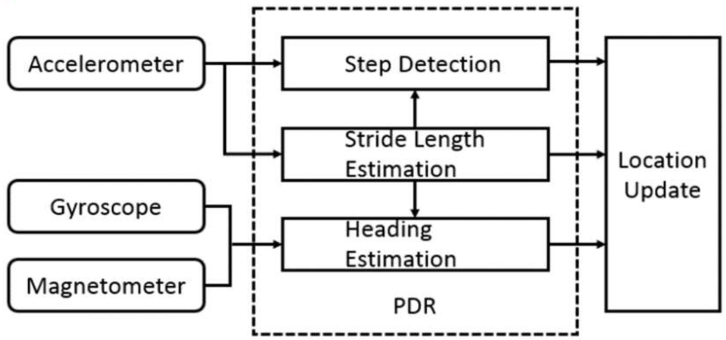
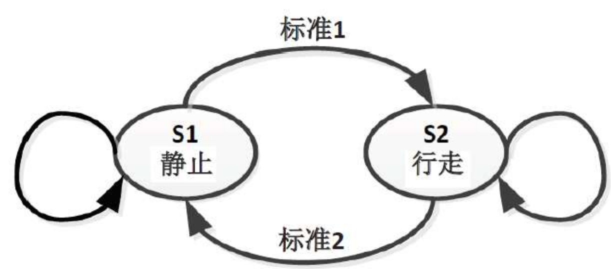
Background

The drift and instability of the smartphone IMU is the most important factor restricting the inertial navigation of the mobile phone. The PDR algorithm used the known human motion model to calculate the dead reckoning, which can dramatically improve the applicability of the IMU. Considering the open bottom GNSS primitive observation of Android, it makes possible to make pseudorange difference algorithm for intelligent terminals, and differential GPS has better advantages in terms of linearization state estimation in noise elimination, and differential GPS without cumulative errors, providing a correction in providing initial values and long-term position estimates. Based on the characteristics of the two positioning modes, this paper proposes a fusion algorithm based on PDR and differential GNSS for real-time indoor and outdoor seamless positioning.



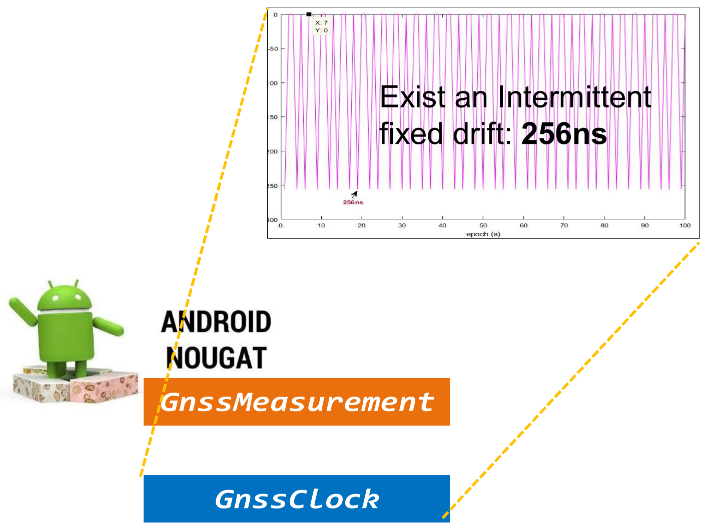
Difference GNSS based on short-line hypothesis

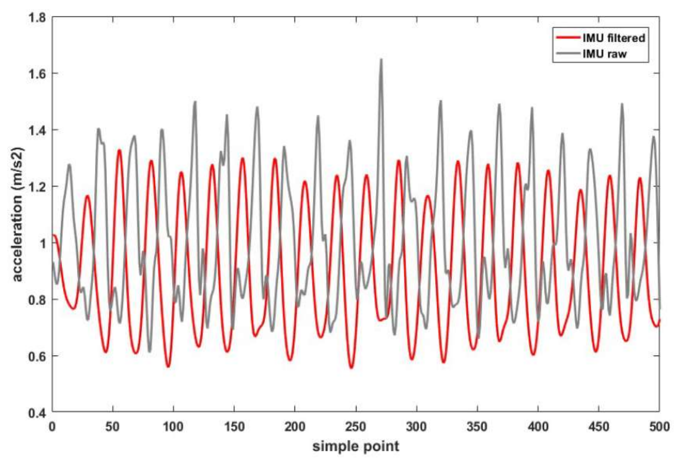




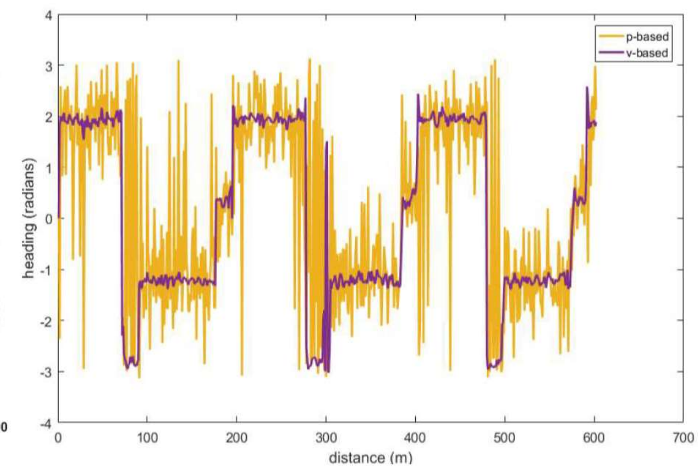
Basic PDR framework

Raw data processing and GNSS heading estimation





IMU data result through Filter



Two GNSS heading estimation comparison

GNSS difference equation

Pseudorange

$I^{(n)} \quad T^{(n)}$

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

subtract $-$

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

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

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

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

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

Doppler

I_r

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

subtract

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

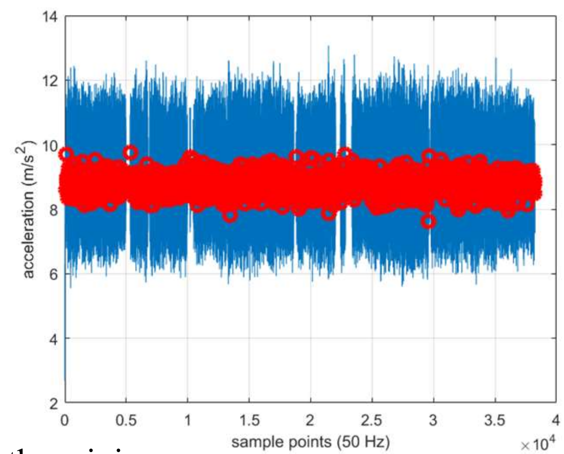
$$\dot{\rho}_{ur}^{(n)} = -v_r \cdot I_r + c\delta f_{ur}$$

Common mode errors are calculated together

PDR algorithm

■Step1：Gait detection

Peak detection algorithm on gait



■Step2：Gait length detection

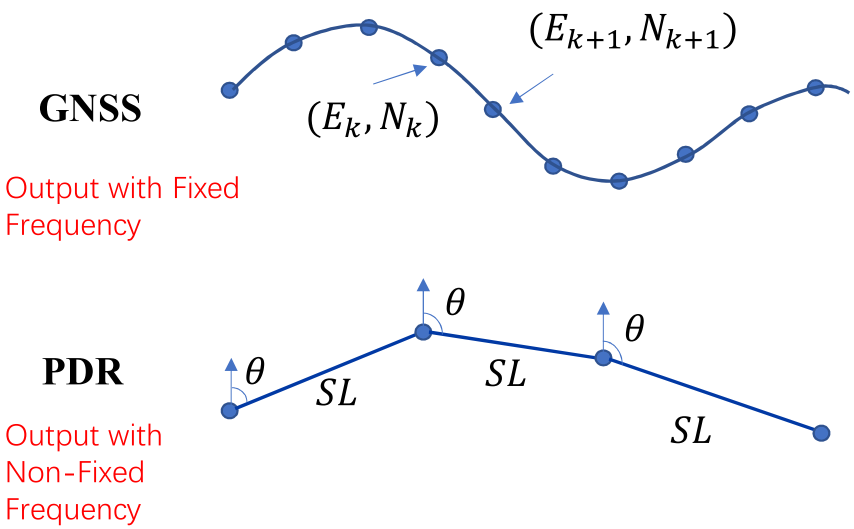
$$S = K \cdot \sqrt[4]{a_M - a_m}$$

K is a constant factor, aM is the peak value of accelerometer, and am is the minimum.

■Step3：Heading estimation

Adopt the Madgwick pose estimation algorithm to obtain the pose, which utilizes the accelerometer and gyro data to construct a error function in ENU axis, uses gradient descent way to calibrate the R, Q and Yaw angle.

GNSS Heading & Stride Length



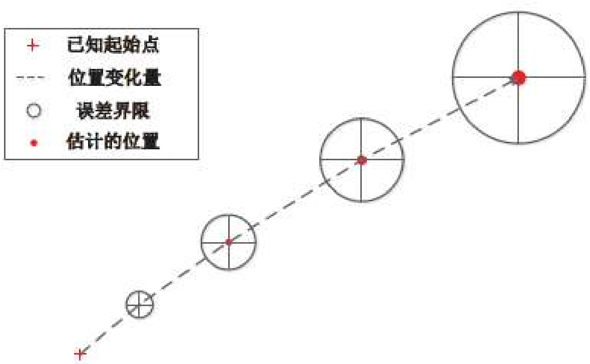
GNSS Heading

$$\theta_{k+1}^{GNSS} = arctan\left(\frac{N_{k+1} - N_k}{E_{k+1} - E_k}\right)$$

GNSS Stride Length

$$SL_{k+1}^{GNSS} = \left\| \begin{bmatrix} E_{k+1} - E_k \\ N_{k+1} - N_k \end{bmatrix} \right\|_2$$

Error of Heading & Stride Length Estimation



Accumulated Error of PDR

Estimation Error is accumulated during iteration!

$$\begin{cases} x_{k+1} = x_1 + \sum_{i=1}^{k} (SL_i \cdot sin\,\theta_i) \\ y_{k+1} = y_1 + \sum_{i=1}^{k} (SL_i \cdot cos\,\theta_i) \end{cases}$$

Another Equations of PDR

Two criteria：

Mean Cumulative Heading Error

$$MCHE(k) = \frac{1}{k}\sum_{i=1}^{k} \varepsilon_k^{\theta-SYS}$$

Cumulative Stride Length Error

$$CSLE(k) = \sum_{i=1}^{k} \varepsilon_k^{SL-SYS}$$

SYS： PDR or GNSS

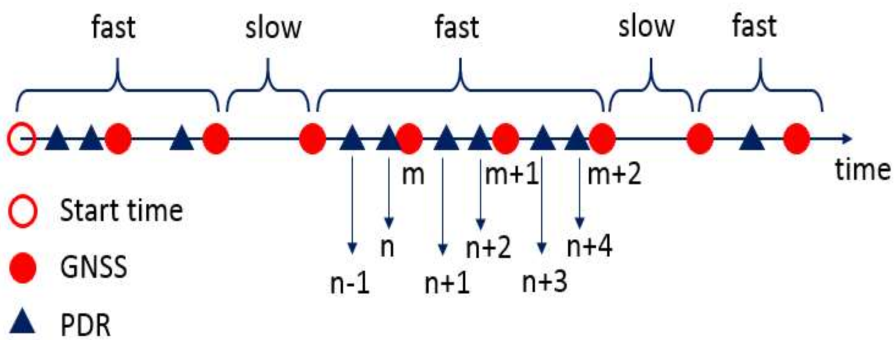
ε_k^{θ}： Heading Estimation Error at time k

ε_k^{SL}： Stride Length Estimation Error

Data Synchronization

fast step： at least one complete step can be completed within 1s

slow step： one complete step cannot be completed within 1s



Data synchronization between PDR and GNSS

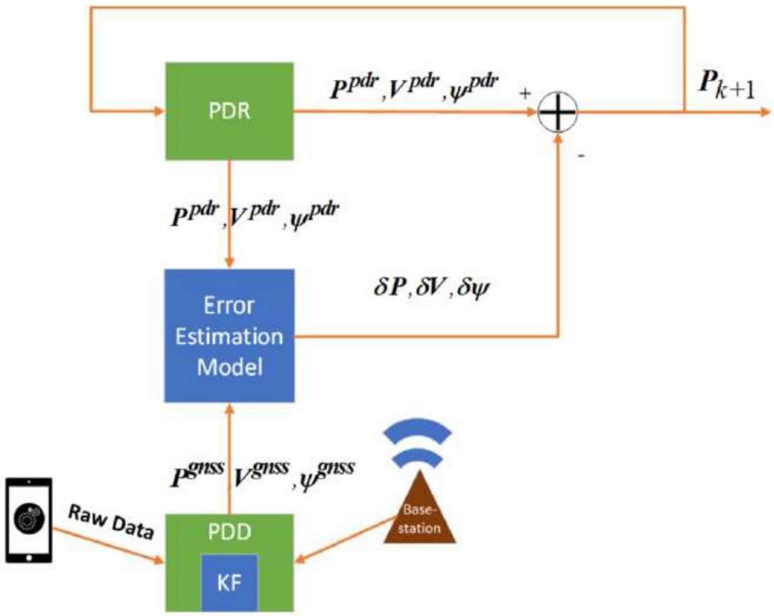
The basic idea of the data synchronization is to turn the data of PDR into a timing output, just like the output of GNSS.

$$\begin{cases} \theta_m = \dfrac{\theta_{n+1} + \theta_{n+2}}{2} \\ SL_m = \sqrt{SL_{n+1}^2 + SL_{n+2}^2 + 2C} \\ C = SL_{n+1} SL_{n+2} \cdot \cos(\theta_{n+1} - \theta_{n+2}) \end{cases}$$

n： step n of PDR

m： time m of GNSS

Fusion Framework



PDR and GNSS fusion algorithm

■Dynamic weight

$$\begin{bmatrix} W \cdot \mathbf{P}^{GNSS} - \mathbf{P}^{PDR} \\ W \cdot \mathbf{V}^{GNSS} - \mathbf{V}^{PDR} \\ W \cdot \varphi^{GNSS} - \varphi^{PDR} \end{bmatrix} = \begin{bmatrix} \delta \mathbf{P} \\ \delta \mathbf{V} \\ \delta \varphi \end{bmatrix}$$

$$W = \sum cnr_i / 50n$$

Experiment Setup and Environment

HUAWEI P10

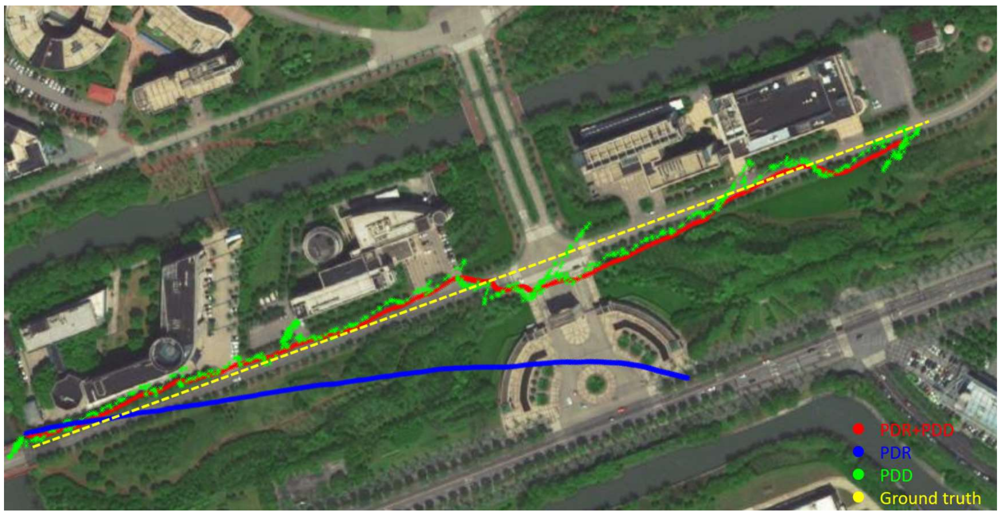
（a）Open filed

(b) Tunnel loop

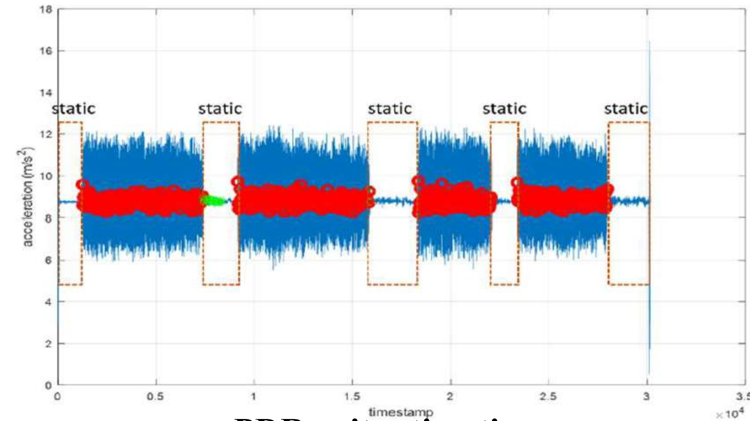
(c) Shade loop

Experiment environments

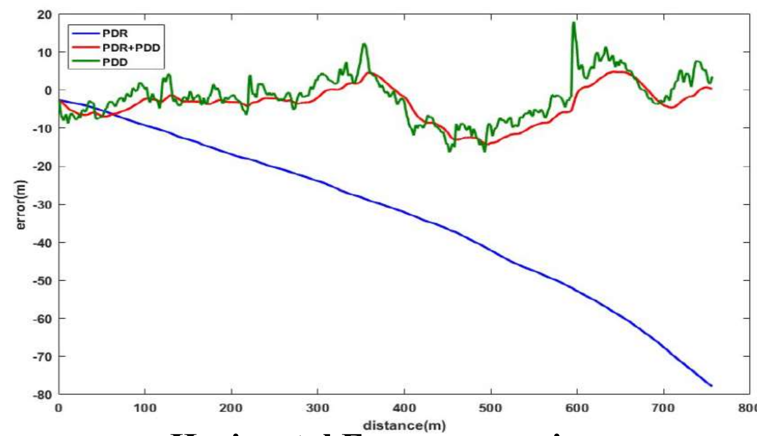
Experiment result



Comparison of trajectories by three method in open filed



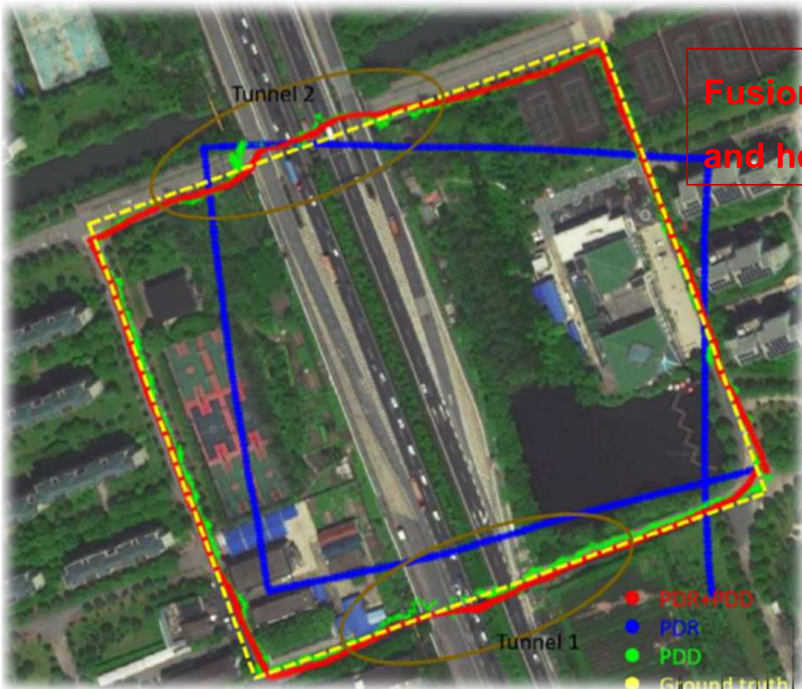
PDR gait estimation



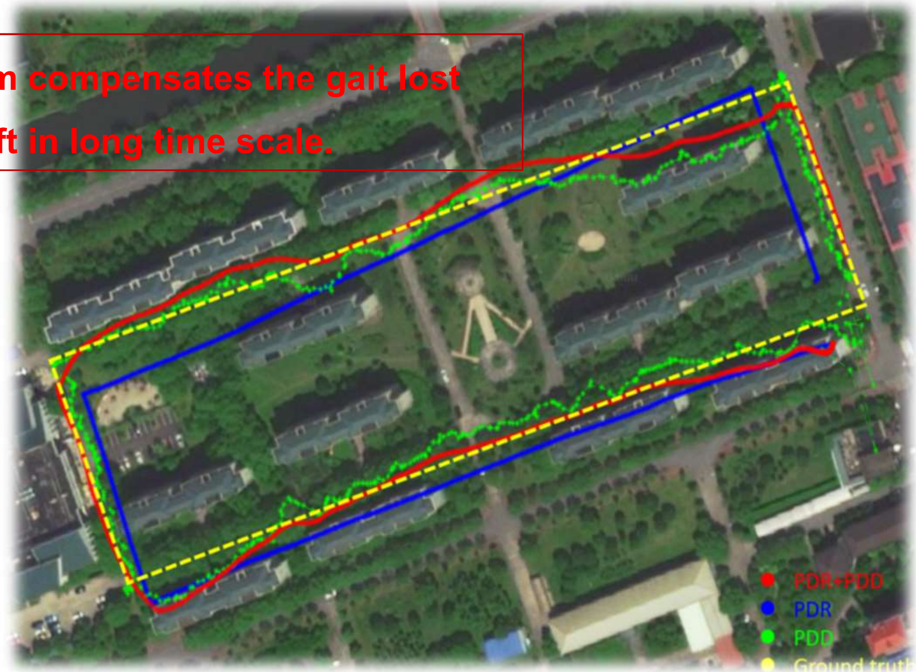
Horizontal Error comparison

Experiment result

Fusion algorithm compensates the gait lost and heading drift in long time scale.



Trajectories in tunnel loop



Trajectories in shade loop

Positioning result

scenario	Error items	PDD	PDR	PDR-PDD
Open road	Mean(m)	4.8	45.2	4.5
	σ(m)	7.4	49	5.2
Tunnel loop	Mean(m)	7.1	71.5	3.2
	σ(m)	8.1	74.2	3.5
Shade loop	Mean(m)	16.2	21.3	8.8
	σ(m)	19.3	22.1	10.7

Algorithm results of different experiments

Conclusion

- Data processing：
  - Promote the pointed pre-processing way based on the smartphone unique signal feature and raw data characteristic.
- PDR/GNSS fusion framework：
  - On the basis of difference GNSS, utilizing the error function on the heading and position layer and real-time feedback to PDR. The key point is the dynamic weight and the choise the error parameters.
- Experiment result:
  - On the condition of dynamic and static alternating motion, short-term signal loss and poor signal quality, the algorithm has its ideal effect. The specified performance that no obvious drift on the scale of 1km, and GNSS signal loss under the tunnel in short time, no error positioning point during the terrible GNSS signal condition. That illustrates in short time scale, the system can play the PDR high-accurate merit, in long time scale, system can calibrate the PDR gain loss and heading drift.

谢谢观赏

THANK YOU