Comprehensive Indoor Information System for Mobile Device

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Introduction

- More than half of the world's population is living in large urban centres and of the population are living and working in indoor environment.

  More accurate or more generalized navigation system is required!

- Indoor Positioning System (IPS) provides navigation services and users data for the Internet of Things (IoT) related researches.
- 3D indoor environment reconstruction function is designed to reconstruct environment around the user in 3D form.
- Fully developed system: 3D real-time Simultaneous Localization and Mapping (SLAM) system for commercial mobile devices

System Design
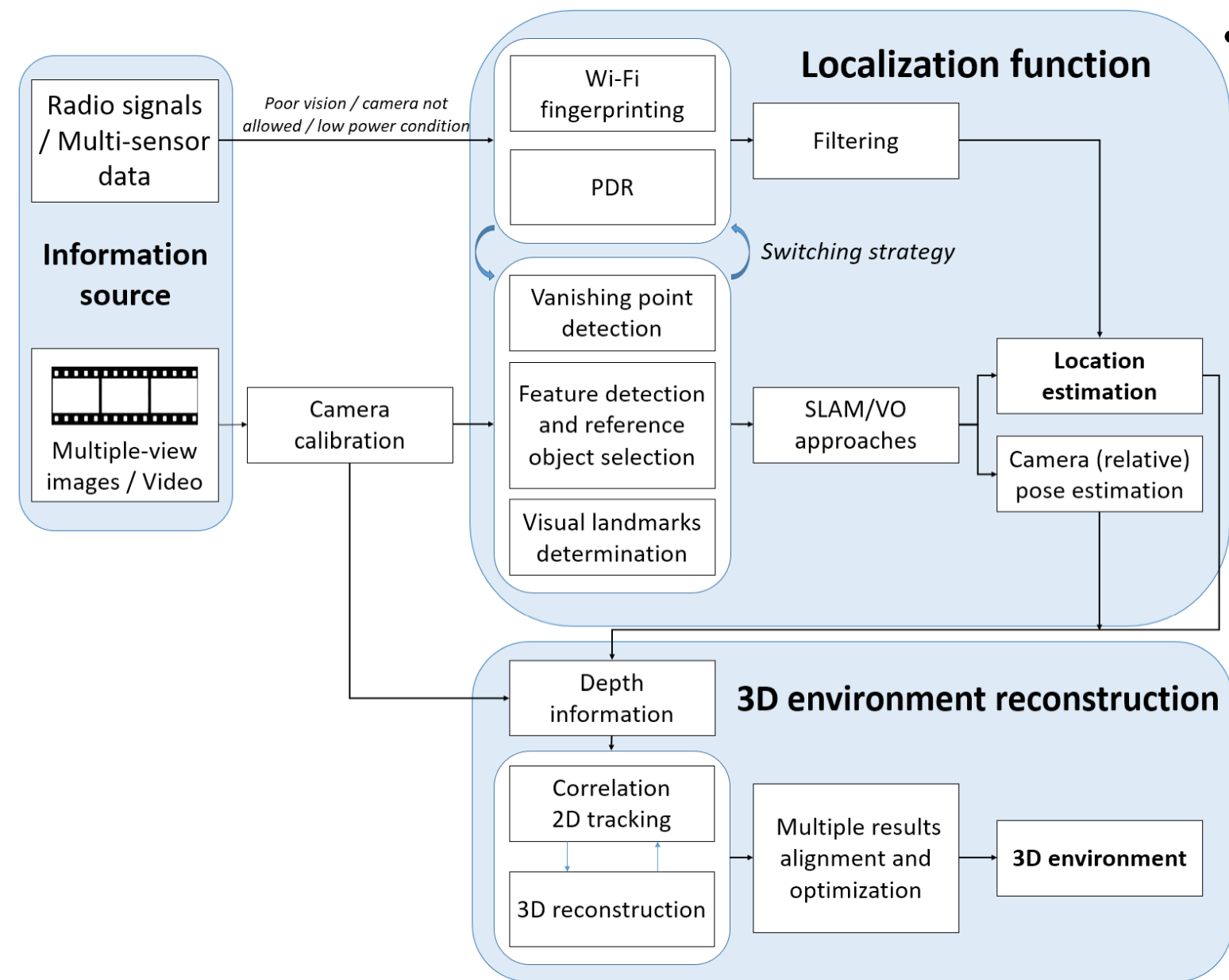
- Based on commercial mobile devices, the system is designed to make use of all available information in indoor environment to implement a robust navigation system as well as a information gathering system.

Radio Signal Based IPS

- Wi-Fi Signal and Magnetic Field Fingerprinting (absolute positioning)

- A radio fingerprint is the pattern of radio signal strength measurements that is observed at a given location.
- Based on pre-established radio fingerprints database, certain matching algorithm will estimate user's position during online matching phase.

- Pedestrian Dead-reckoning (PDR) (relative positioning)

- Dead reckoning is a navigation method using sensor data based on step detection and heading estimation to estimate the trajectory of human or robot.
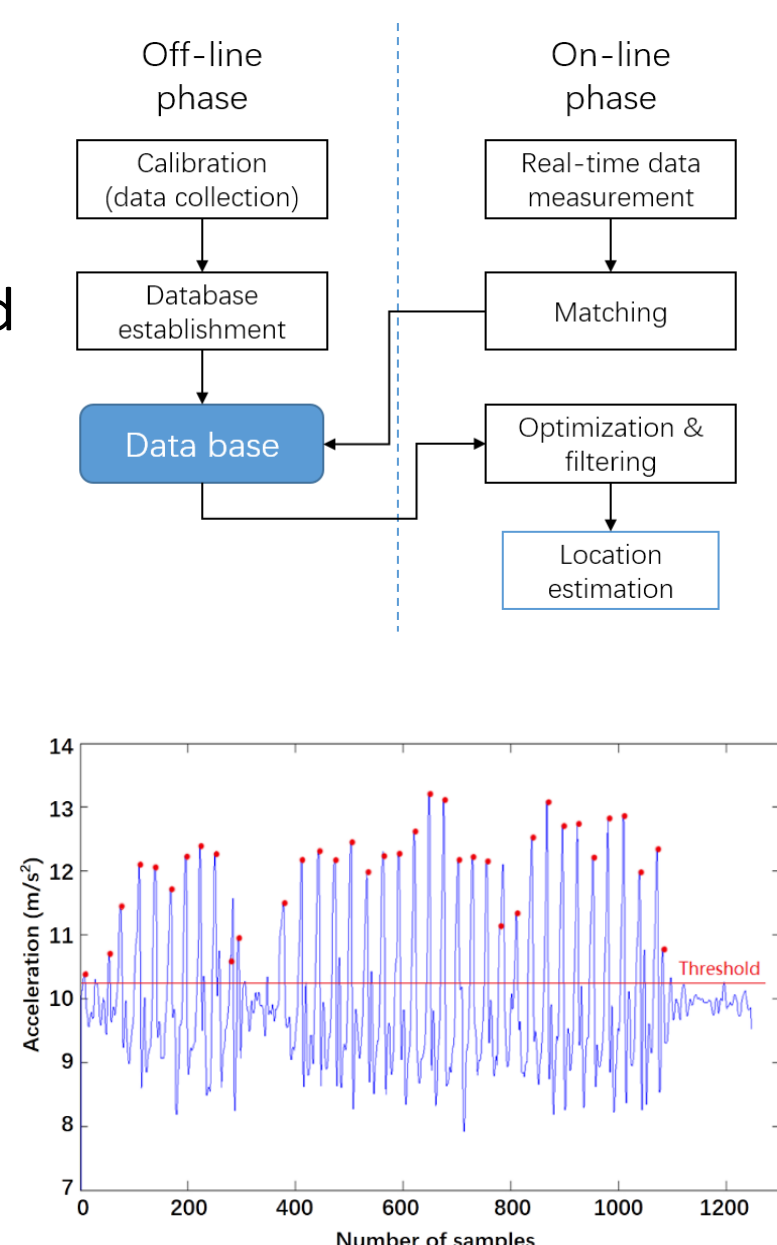

Image Information Based IPS

- Simultaneous Localisation and Mapping (SLAM)
- The whole process of SLAM can be described as a loop with three tasks: tracking, mapping, and loop closing.

- The SLAM problem can be described in probabilistic form as a two-step recursive prediction and correction problem

$$P(x_t, m \mid z_{0:t-1}, u_{0:t}, x_0) = \int P(x_t \mid x_{t-1}, u_t)P(x_{t-1}, m \mid z_{0:t-1}, u_{0:t-1}, x_0)dx_{t-1}$$

$$P(x_t, m \mid z_{0:t}, u_{0:t}, x_0) = \frac{P(z_t \mid z_t, m)P(x_t, m \mid z_{0:t-1}, u_{0:t-1}, x_0)}{P(z_t \mid z_{0:t-1}, u_{0:k})}$$

- Visual-based SLAM (V-SLAM):

- Based on Structure from Motion (SfM) and Visual odometry (VO)
- Feature detection and camera relative position estimation.
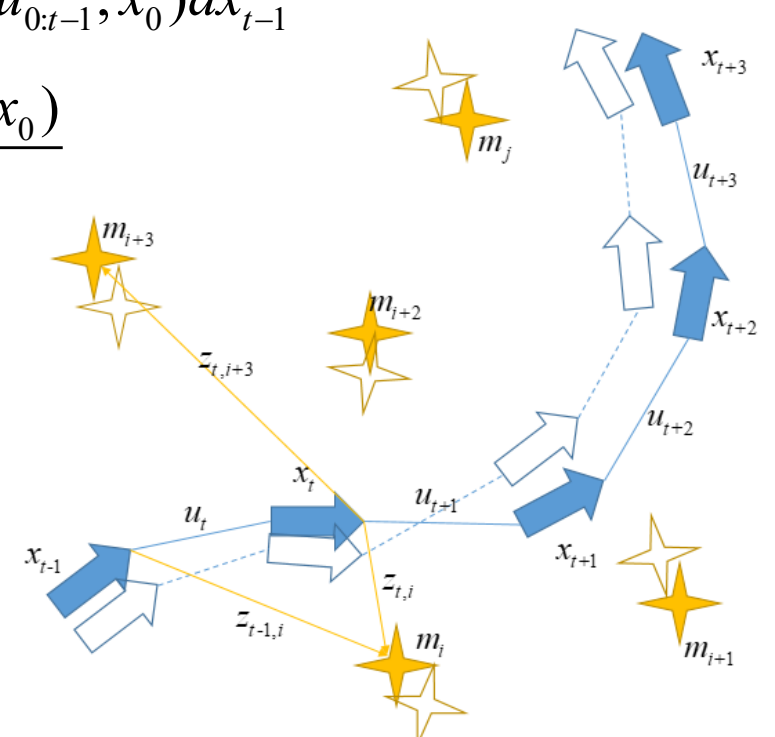
Filtering Technologies & Environment reconstruction principle

- Recursive Bayes Filter

  Prediction

  $$bel'(x_t) = \int_{x_{t-1}} P(x_t \mid x_{t-1}, u_t)bel(x_{t-1})dx_{t-1}$$

  Correction

  $$bel(x_t) = \eta P(z_t \mid x_t)bel'(x_t)$$

- Kalman Filter

  Extended Kalman Filter (EKF)
  Unscented Kalman filter (UKF)

- Particle Filter

  Monte-Carlo localisation

- Rao-Blackwellized localisation

  Particle filter for trajectory optimisation and EKF for Landmarks information updating
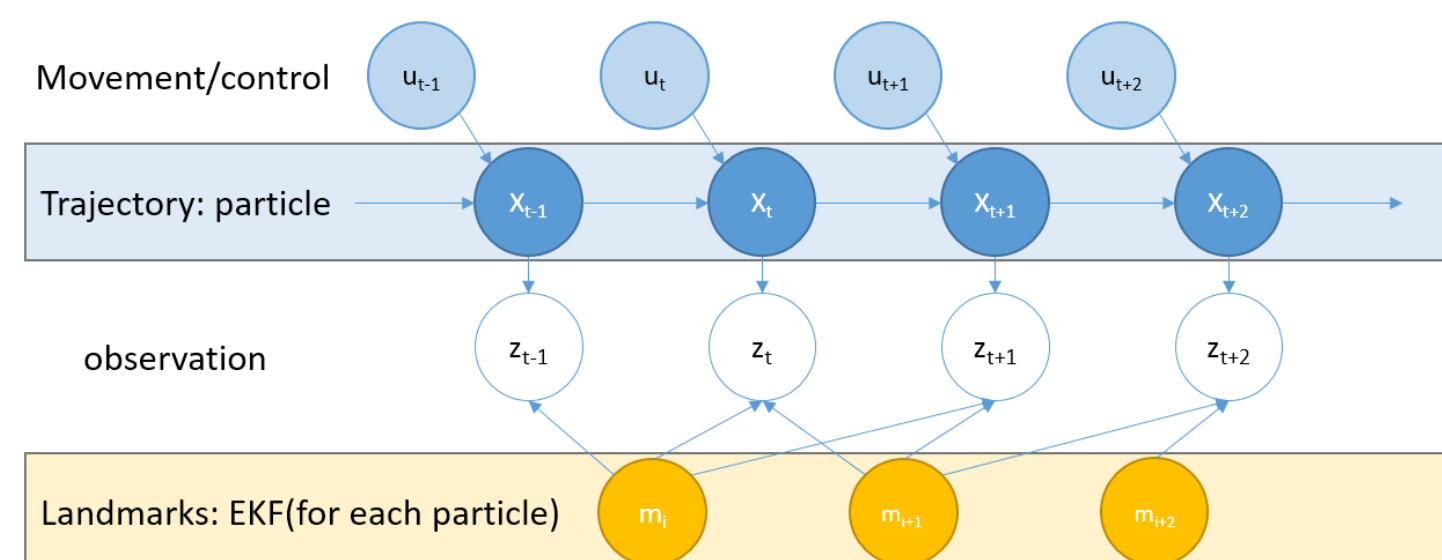
- Euclidean 3D Reconstruction
- Euclidean reconstruction can be applied in condition of calibrated camera with known relative pose of two cameras.

$$s_1 m_1 = K_1 R_1^T (M - C_1) \quad and \quad s_2 m_2 = K_2 R_2^T (M - C_2)$$
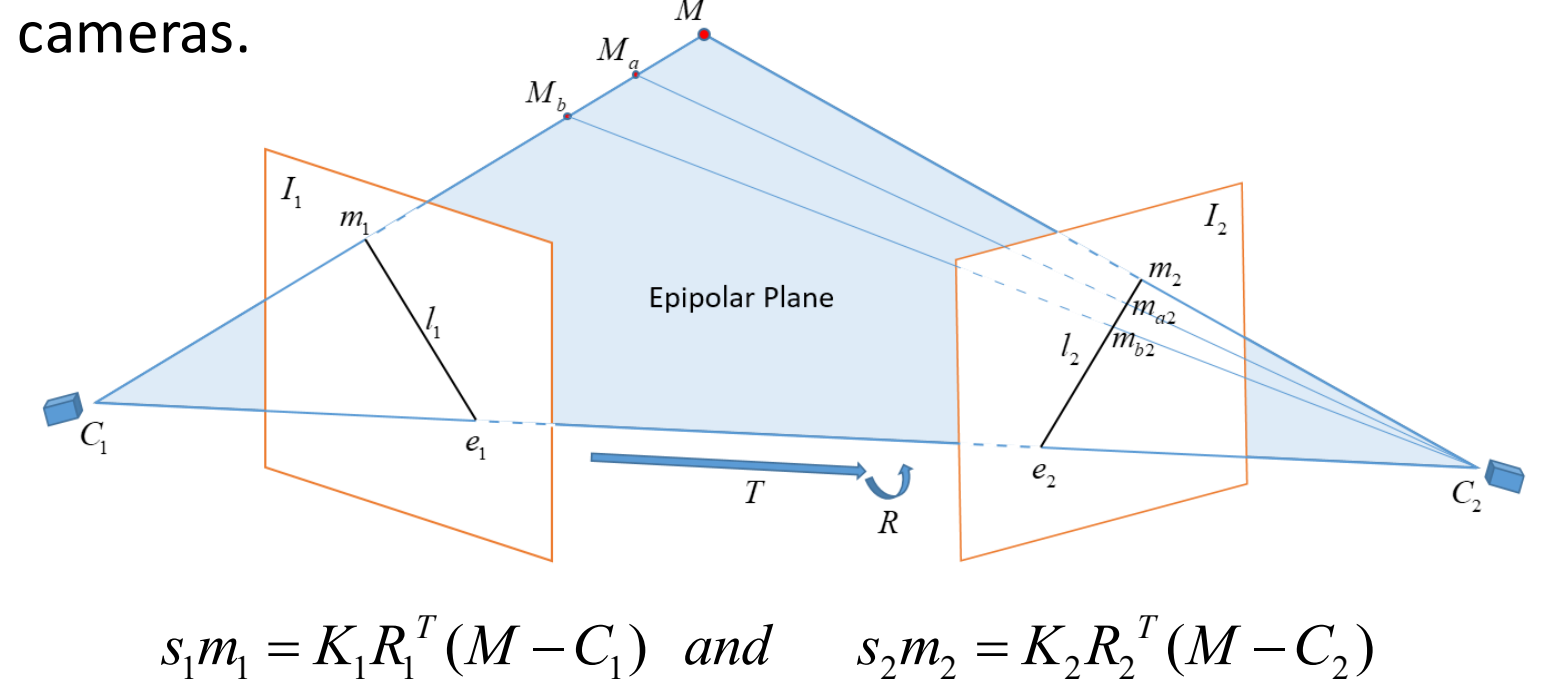
Current Progress & Future work

- Radio signal based IPS
- Currently, a fully implemented real time navigation system based on Wi-Fi fingerprinting and PDR has been tested in real underground station and the system performance are presented as follow:

System performance	Off- peak time		Peak time	
	Matching result	Filtered result	Matching result	Filtered result
Overall average error distance	2.37 m	**1.71 m**	3.42 m	**2.90 m**
80% CDF error distance	< 2.91 m	**< 2.54 m**	<4.77 m	**<4.2 m**

- The error distance 80% CDF for traffic peak time is under 4.8 m and for Off-peak situation is under 2.6 m, which has reached the top accuracy of complicated indoor environment positioning research.
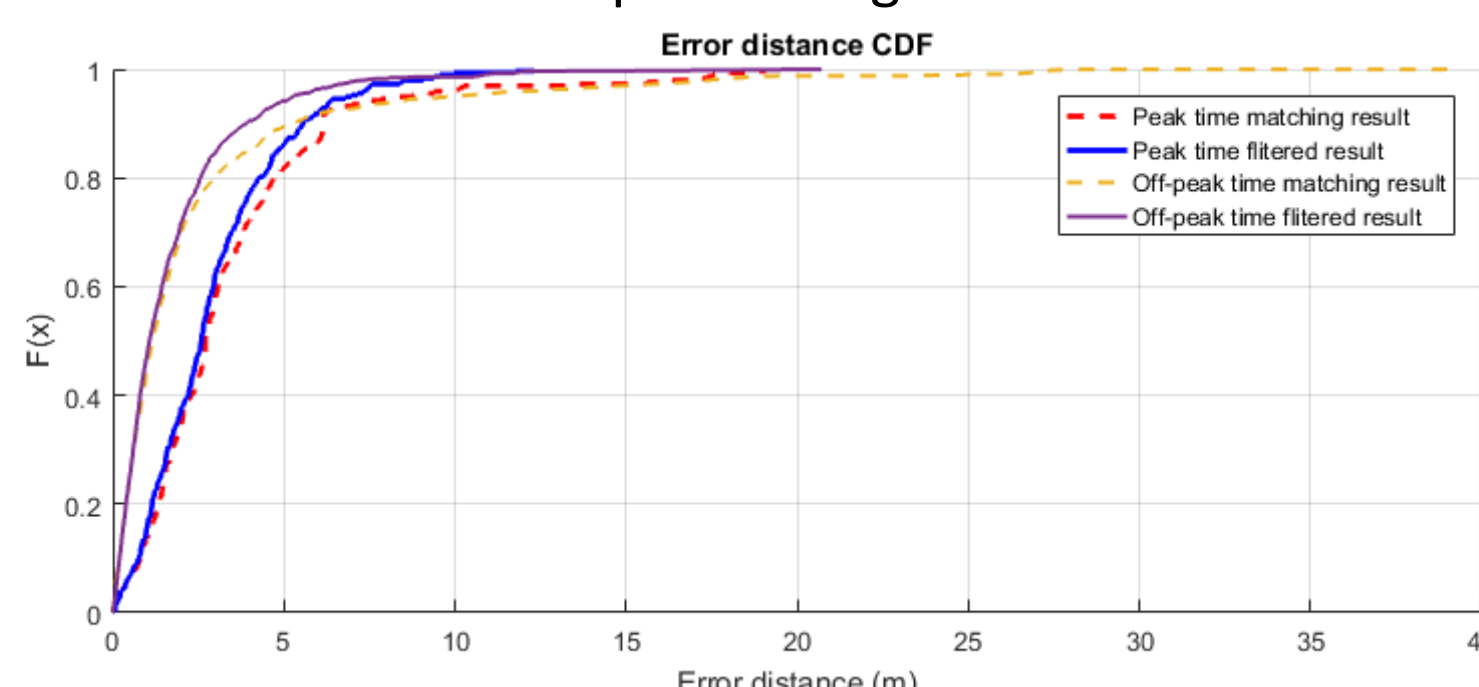
- Future work
- 3D environment reconstruction part is still under development. The combination of image information will greatly improve the accuracy of current system.
- The image information will be a good standard for different mobile devices, so that a big data databased of radio signal information can be constructed.