FastSLAM: Outdoor Implementation with Known and Unknown Data Association

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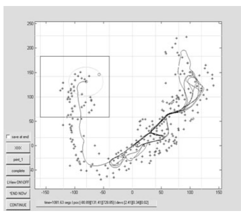
SLAM in Large Environments :

- **CEKF**
  - Solve the problem for high frequency sensors in local areas
- **Decorrelation Techniques**
  - Address the problem of full update and memory requirements
- **Cluttered Environments:**
  - Data association will be a continuous problem



FastSLAM

- **Probabilistic Motion Model** $\boxed{p(x_t / u_t, x_{t-1})}$
- **Measurement Model** $\boxed{p(z_t / x_t, \theta, n_t)}$
- **SLAM Problem** $\boxed{p(x^t, \theta / z^t, u^t) \quad time:1..t}$
- **If the path of the robot is known then all individual landmarks estimation problems are independent**

FastSLAM

- **Decomposes the SLAM problem into a localization problem and a number or landmark estimation problems conditioned on the robot pose estimate**
  - Uses a particle filter to estimate the posteriori over the robot paths.
  - Each Particle possesses k Kalman filters that estimate the k landmarks location conditioned on the path estimate.
  - The computational requirement will be O(M*k) with M and k the number of particles and landmarks respectively

FastSLAM

- **The slam Problem can be decomposed into K+1 estimation problems:**
  - Posteriori over the robot path
  - K problems estimating the location of the landmarks

$$p(x^t,\theta / z^t,u^t) = p(x^t / z^t,u^t)\prod_k p(\theta_k / x^t,z^t,u^t)$$

- **The Robot path estimation is implemented with a particle filter**
- **The landmark positions are estimated with Kalman Filters**

$$p(x^t / z^t,u^t)$$

$$p(\theta_k / x^t,z^t,u^t)$$

- **The full posteriori of path and landmark is represented by the following sample set**

$$X_t = \{x^{t,[m]}, \overline{\theta}_1^{[m]}, P_{\theta_1}^{[m]} ......\overline{\theta}_K^{[m]}, P_{\theta_K}^{[m]}\}$$

Known Data Association

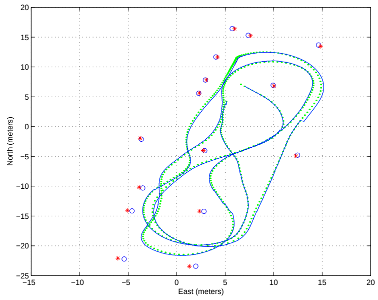
- **The Experimental results are done with real data**
- **It is not possible to "measure" correspondence (Data association)**
- **The data association was implemented by a KF based SLAM**
  - Landmarks were extracted
  - Once accepted, they were included in a list with appropriate time stamp
  - This list has the observations used by FastSLAM

Known Data association

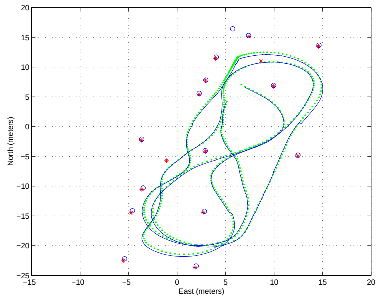
Experimental Runs

- **Car Park**
  - Beacon consisted of 60 mm steel poles
  - Clearly defined and easily extracted from the environment
  - Accurate Determination of landmark Position

EKF and FastSLAM Map and Trajectory

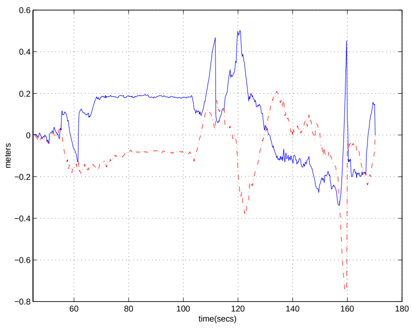


EKF SLAM

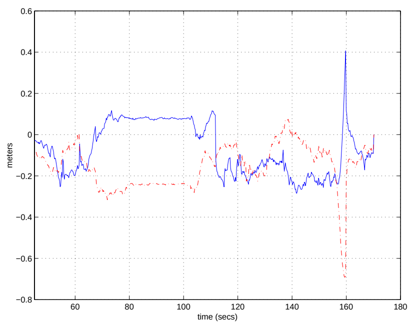


FastSLAM

EKF and FastSLAM absolute Error



EKF SLAM



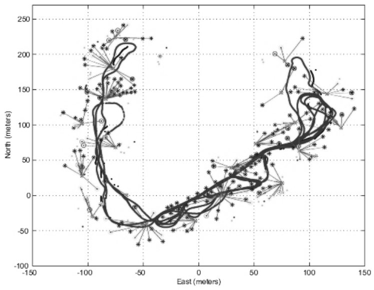
FastSLAM

Known Data association

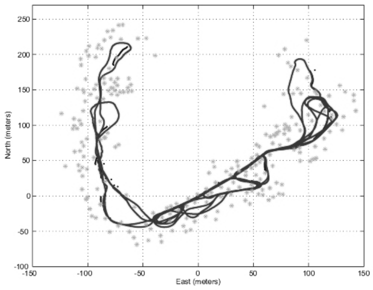
Experimental Run:

- **Victoria park**
  - Large Environment
  - Different type of landmark
  - Larger errors in landmark position determination

Known Data Association



EKF SLAM



FastSLAM

FastSLAM: Victoria Park

Unknown Data Association

Data Association Problem:

- **Associating the observation to the correct state**
- **Initializing new tracks**
- **Detecting and rejecting spurious measurements**

$Beacon = \min(innov \cdot S^{-1} \cdot innov^{T} + \ln(|S|))$

Unknown Data Association

Principle of Data Association

- **Innovations sequence** $\boxed{\nu_{ij}(k) = z_i(k) - \hat{z}_j(k)}$
- **Normalised Innovations sequence** $\boxed{d_{ij}^2(k) = \nu_{ij}^T(k) S_{ij}^{-1}(k) \nu_{ij}}$

$Beacon = \min(innov \cdot S^{-1} \cdot innov^{T} + \ln(|S|))$

$w_t^{[m]} \propto \int p(z_t \mid \theta_{n_t}^{[m]}, s_t^{[m]}, n_t)\, p(\theta_{n_t}^{[m]})\, d\theta_{n_t}$

Unknown Data Association

- **Gate Validation: Associate only if there is one possible hypothesis**
- **Nearest Neighbour: Select the "nearest" state to the observation**
- **Multi Hypothesis Tracking: Use all the possible hypothesis**

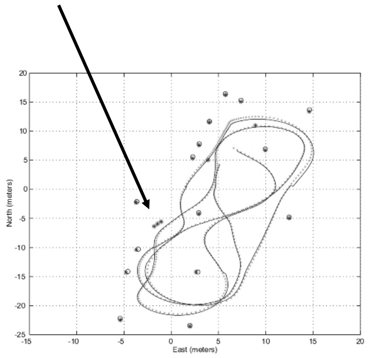
Unknown Data Association

Multi Hypothesis Tracking

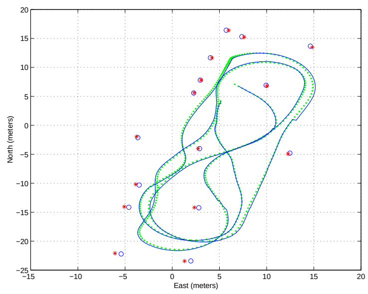
- **EKF Slam:**
  1. Run a new filter in parallel
  2. Pruning Techniques
- **FastSlam**
  1. Create a new particle
  2. Resampling

Experimental Results Car Park

Additional Landmarks

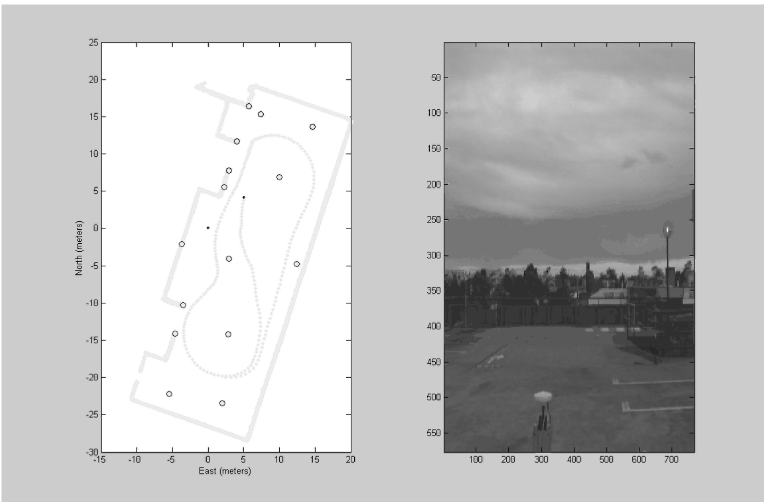


FastSLAM

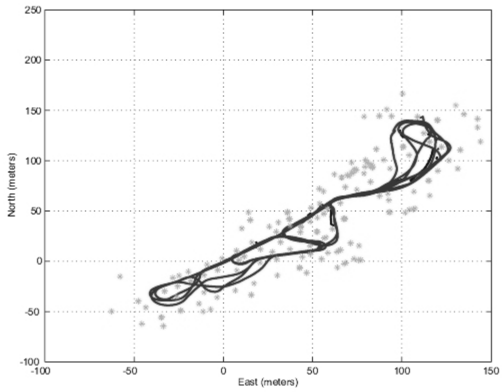


EKF SLAM

Experimental Results Car Park



Experimental Results Victoria Park



Eduardo Nebot Hybrid Navigation Architecture

Current Research

- **Data Association**
  - Multiple Hypothesis
    - H1-n: All Possible Existing Landmarks
    - Ho : Spurious measurement
    - Hn : New object
  - Control of number of Particles
- **Addressing the covariance reduction Problem**
- **Consistency**
- **Extension to larger systems**

Eduardo Nebot Hybrid Navigation Architecture

Experimental Results Car Park