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Kalman Filter SLAM

State:	x	Time Step:	k
Input:	u	Process Noise:	v
Output:	y	Measurement Noise:	w

Linear Kalman Filter

$$\begin{aligned} x(k+1) &= F(k)x(k) + G(k)u(k) + v(k) \\ y(k) &= H(k)x(k) + w(k) \end{aligned}$$

prediction:

$$\begin{aligned} \hat{x}(k+1|k) &= F(k)\hat{x}(k|k) + G(k)u(k) \\ P(k+1|k) &= F(k)P(k|k)F(k)^T + V(k) \end{aligned}$$

update:

$$\begin{aligned} \hat{x}(k+1|k+1) &= \hat{x}(k+1|k) + R\nu \\ P(k+1|k+1) &= P(k+1|k) - RH(k+1)P(k+1|k) \end{aligned}$$

where

$$\begin{aligned} \nu &= y(k+1) - H(k+1)x(k+1|k)) \\ S &= H(k+1)P(k+1|k)H(k+1)^T + W(k+1) \\ R &= P(k+1|k)H(k+1)^T S^{-1}. \end{aligned}$$

Extended Kalman Filter

Kalman Filter for nonlinear systems where F and H are linearized about the current state estimate

$$F(k) = \left.\frac{\partial f}{\partial x}\right|_{x=\hat{x}(k|k)} \qquad H(k+1) = \left.\frac{\partial h}{\partial x}\right|_{x=\hat{x}(k+1|k)}$$

Simultaneous Localization and Mapping

Use Kalman Filter to simultaneously estimate position of robot and landmarks in environment

$$x = \begin{bmatrix} x_r & y_r & x_{\ell 1} & y_{\ell 1} & x_{\ell 2} & y_{\ell 2} & \dots & x_{\ell n_\ell} & y_{\ell n_\ell} \end{bmatrix}^T$$

Linear Relative Position Output:

$$y_i(k) = \begin{bmatrix} x_{\ell i}(k) - x_r(k) \\ y_{\ell i}(k) - y_r(k) \end{bmatrix} + w_i(k)$$

Nonlinear Range and Bearing Output:

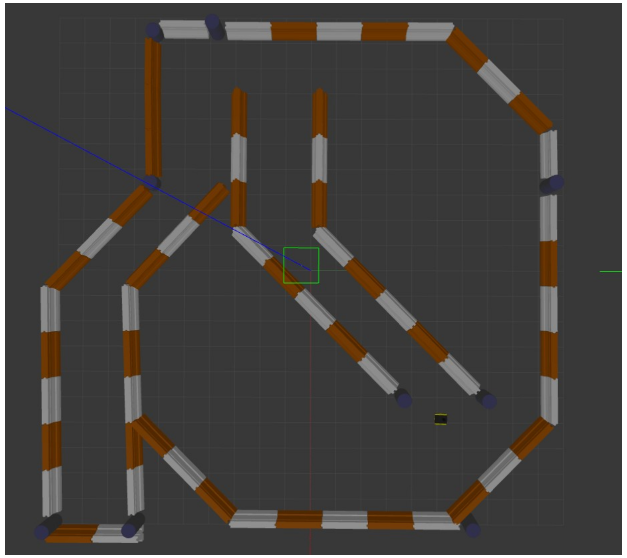
$$y_i(k) = \begin{bmatrix} \sqrt{(x_{\ell i}(k) - x_r(k))^2 + (y_{\ell i}(k) - y_r(k))^2} \\ \operatorname{atan2}((y_{\ell i}(k) - y_r(k)), (x_{\ell i}(k) - x_r(k)) - \theta_r(k) \end{bmatrix} + w_i(k)$$

Data Association

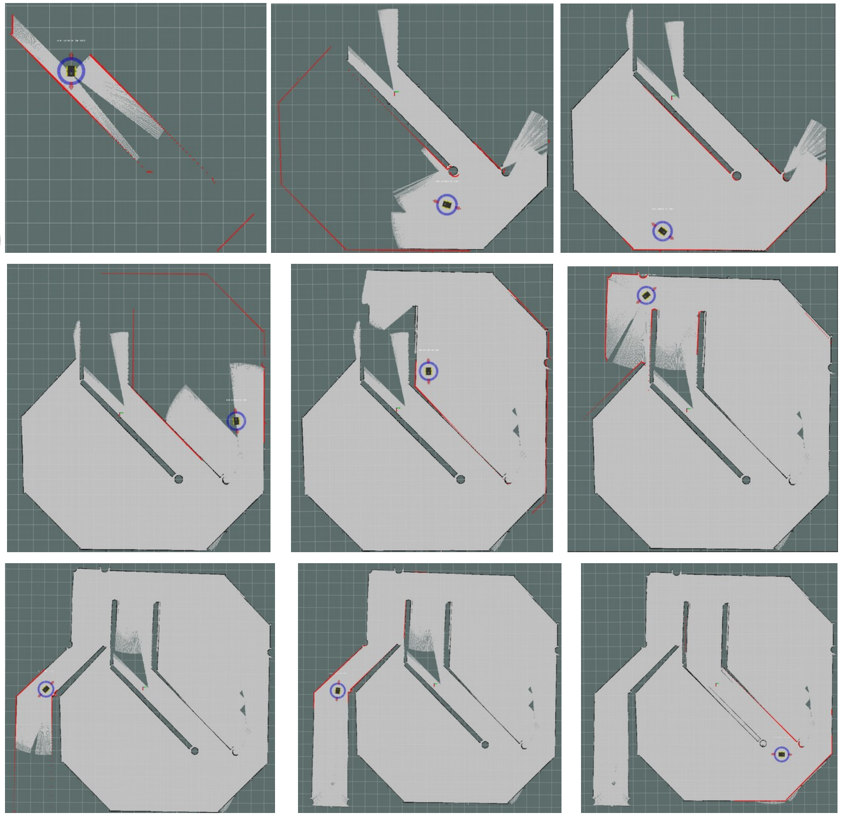
Which landmark is each measurement associated with?

Use Mahalanobis Distance

$$\chi_{ij}^2 = (y(k)_i - h(k)_j)^T S_{ij}(y(k)_i - h(k)_j)$$



ROS gmapping in Jackal Simulator



Source: Principles of Robot Motion: Theory, Algorithms, and Implementations Ch. 8 – Choset et. al.