SLAM IN AIR VEHICLE APPLICATIONS

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Centralised Data Fusion

- Excessive Communication Bandwidth
- Excessive Computational Expense
- Low Level of Integrity

Decentralised Data Fusion

- Increased Integrity
- Reduction in computation and communication expense
- Wider coverage area
- Results are obtained quicker
Physical System

Flight Platforms

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Radar Sensor

Simultaneous Localisation and Map Building
SLAM

- Highly non-linear
- 6DoF Estimation
- Information is only $2^{1/2}$D
- Observability Issues

- Standard Cartesian
- Raw Fusion
SLAM – Error Analysis

\[ \delta \mathbf{p}_s^T = \mathbf{p}_s - \mathbf{p}_s' \]

\[ \delta \mathbf{P}_s^T = \delta \mathbf{V}_s' \]

\[ \delta \mathbf{V}_s^T = \mathbf{C}_s f_s' \delta \mathbf{p}_s^T + \mathbf{C}_s' \delta f_s' \]

\[ \delta \mathbf{V}_s^T = -\mathbf{C}_s' \delta \omega_s' \]

\[ \delta x(k) = | \mathbf{x}(k) \mathbf{p}_1^T(k) \mathbf{p}_2^T(k) \cdots \mathbf{p}_n^T(k) |^T \]
INS/SLAM - Observation

- Non-linear observation model
- Observation Model
  - In Cartesian coordinate
  - In Spherical coordinate

\[ z(t) = h(x(t)) + v(t) \]

\[ z_{\text{cartesian}} = \begin{bmatrix} x \ y \ z \end{bmatrix}^T = p_s \]
\[ = C_s^{bT} C_s^{aT} [p_n^e - p_b^e - C_b^{ts} p_s^b] \]

\[ z_{\text{spherical}} = \begin{bmatrix} r \ \psi \ \theta \end{bmatrix}^T = g_s(p_s^0) \]
\[ = \begin{bmatrix} \sqrt{x^2 + y^2 + z^2} \\ \tan^{-1}(y/x) \\ \tan^{-1}(z/\sqrt{x^2 + y^2}) \end{bmatrix} \]

- Jacobian In Cartesian coordinates
\[ H_{\text{cartesian}} = \nabla h = \begin{bmatrix} -e_1^g e_3^g & 0_{6 \times 3} & \frac{\partial g_s}{\partial \psi} & \cdots & (C_s^{\psi \theta} C_s^{g})^T & \cdots \end{bmatrix} \]

- Jacobian In Spherical coordinates
\[ H_{\text{spherical}} = \nabla \hat{h} = \nabla g_s \hat{g} \]
\[ = \begin{bmatrix} \frac{\partial}{\partial \psi} & 0 & 0 \\ \frac{\partial}{\partial \theta} & 0 & 0 \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \psi} & \frac{\partial}{\partial \theta} \end{bmatrix} \begin{bmatrix} -e_1^g e_3^g & 0_{6 \times 3} & \frac{\partial g_s}{\partial \psi} & \cdots & (C_s^{\psi \theta} C_s^{g})^T & \cdots \end{bmatrix} \]
**INS/SLAM - EKF**

- **EKF formulation**
  \[ x_{k+1} = f(x_k, u_{k+1}) + w_k \]
  \[ z_k = h(x_k) + v_k \]

- **Prediction**
  \[ x_{k+1} = f(x_k, u_{k+1}) \]
  \[ P_{k+1|k} = \nabla_x f_k P_{k|k} \nabla_x f_k^T + \nabla_u f_k U_k \nabla_u f_k^T + Q_k \]

- **Update**
  \[ v_k = z_k - h(x_k) \]
  \[ S_k = \nabla_x h P_{k+1|k} \nabla_x h^T + R_k \]
  \[ W_k = P_{k+1|k} \nabla_x h^T S_k^{-1} \]
  \[ x_{k+1|k+1} = x_{k+1|k} + W_k v_k \]
  \[ P_{k+1|k+1} = P_{k+1|k} - W_k S_k W_k^T \]

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**INS/SLAM - EKF**

- **Data association**
  \[ v_k^T S_k^{-1} v_k \leq d_{min} \]

- **New feature Augmentation**
  \[ x_{new} = \begin{bmatrix} x_k \\ g(x_k, z_k) \end{bmatrix} \]
  \[ P_{new} = \begin{bmatrix} 1 & 0 \\ \frac{\partial g}{\partial x} & \frac{\partial g}{\partial z} \end{bmatrix} P_k \begin{bmatrix} 0 & 0 \\ 0 & R_k \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \frac{\partial g}{\partial x} & \frac{\partial g}{\partial z} \end{bmatrix}^T \]
### INS/SLAM

**Observation in Spherical vs. Cartesian coordinate**

<table>
<thead>
<tr>
<th>Spherical</th>
<th>Cartesian</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-linear observation model</td>
<td>Linear observation model</td>
</tr>
<tr>
<td>Un-correlated observation (range, bearing, elevation)</td>
<td>Correlated observation (x,y,z)</td>
</tr>
<tr>
<td>Suitable for single-platform tracking</td>
<td>Suitable for multi-platform tracking</td>
</tr>
</tbody>
</table>

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INS/GPS vs. INS/SLAM
Difference between INS/GPS and INS/SLAM

- Sharing of Map Information
- Mixture of State and Information forms
Future

- Knowledge
- Action
- Cooperation & Coordination
- Systems of Systems
- Reasoning about the Knowledge of a System and its Capability
Short SLAM

Linking GPS to SLAM
Autonomous SLAM

- Need to assure integrity of navigation system is exceptional in order to close the loop
- Decision Time
  - Exploration or Exploitation
  - Future Horizon
  - Hybrid Control

Non-Gaussian Fusion and Control
Mutual information gain
- Expected information gain is communicated
- Local knowledge of global information

Trajectory control localised based on maximising global utility
Air-Ground DDF and DCC

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