Robust Adaptive Terrain Relative Navigation

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Localization

- Localization without infrastructure
- No GPS for many motivating missions

Source: marsrover.nasa.gov
Terrain-Relative Navigation (TRN)

- **Stand-alone localization**

- **Requirements**
  - Map of terrain
  - Measurements of terrain

- **Correlate measurements against map to estimate terrain-relative position**

- **Started as cruise missile guidance**
  - TERCOM – Terrain Contour Matching (Golden 1980)

- **Meter-level AUV localization**
TRN Challenge: Flat Terrain

- Uncertainty can decrease too quickly in flat terrain
- Result: Overconfidence
- Potential Risk
  - Path planning
  - Obstacle avoidance
TRN Correlation

Measurements

Map

Probability Model

Meas. Model

Map Model

Terrain Model

Position Likelihood

\[
p(z, \hat{m} | x) = \eta \exp \left( \frac{1}{2} \left( \frac{z - \hat{m}_x}{\sigma^2_{\text{sensor}}} + \frac{\hat{m}_x}{\sigma^2_{\text{map}}} \right)^2 \right)
\]

\[
p(x | z, \hat{m})
\]
Terrain Model

- $p(m)$ encodes terrain statistics
  - Degree of terrain correlation
  - Uncorrelated terrain model = high assumed SNR

- Standard terrain model
  - Over-confident in flat terrain

- Improved terrain model
  - Correct confidence
  - Computationally intractable for large maps
TRN Correlation

Measurements

Map

\[ z, \hat{m} \]

\[ \eta \left( \int p(z|x, m)p(\hat{m}|m) p(m) \, dm \right) \]

\[ p(x|z, \hat{m}) \]

\[ p(z, \hat{m}|x) \]
Method 2: Approximating the Result

- Start with standard TRN estimator
  - Unbiased

- Adjust variance to match

\[ p_{\text{approx}}(z, \hat{m}|x) = p_{\text{nominal}}(z, \hat{m}|x)^\alpha \]

- Adjustment estimated from map
Estimating Variance Adjustment

\[ p_{\text{approx}}(z, \hat{m}|x) = p_{\text{nominal}}(z, \hat{m}|x)^{\alpha} \]

- **Degree of adjustment depends on terrain**
  - Flatter terrain \( \rightarrow \) More adjustment

\[ \alpha = \frac{(\sigma_{\text{sensor}}^2 + \sigma_{\text{map}}^2)\tilde{\delta}^2}{(\sigma_{\text{sensor}}^2 + \sigma_{\text{map}}^2)(\tilde{\delta}^2 + \sigma_{\text{map}}^2) + \sigma_{\text{sensor}}^2\sigma_{\text{map}}^2} \]

\[ \tilde{\delta}_k^2 = \text{Var}(m_x) \]

- **Adjustment estimated from map**

\[ \hat{\delta}_k^2 = \text{Var}(\hat{m}_x) - \sigma_{\text{map}}^2 \]

- **Small computational burden**
AUV Demo

- Kearfott INS – Provides motion update
- RDI 300 kHz DVL – Provides range measurements
- Test region: flat area near Soquel Canyon
AUV TRN Demo

Nominal Filter

Robust Adaptive Filter

Northing (m) from 4074348 m

Eastings (m) from 591348 m

True Map-Relative

TRN Estimate

Uncertainty

Northing (m) from 4074348 m

Eastings (m) from 591348 m

True Map-Relative

TRN Estimate

Uncertainty
Gradient TRN Demo

- ATRV-Jr
  - Differential drive
  - Encoders, IMU, Magnetometer
Gradient TRN Demo

Run Time 9.99s

- Particles
- GPS

1900 1950 2000 2050 2100 2150 2200 2250 2300
1250 1300 1350 1400 1450 1500 1550 1600

Color Scale:
- 34
- 36
- 38
- 40
- 42
- 44
- 46
- 48
- 50
- 52
Conclusion

- Terrain Relative Navigation is susceptible to false convergence in flat terrain.

- Flattening probabilities as a function of estimated terrain information can improve robustness in flat terrain.
Questions?