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Outline

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Introduction

• Terrain Based Navigations refers to the general problem of localizing a robot in the environment with the aid of known a-priori map of the terrain.
  – Terrain Relative Navigation
  – Terrain Aided Navigation

• The purpose is increasing the estimation accuracy of the position of the vehicle
  – Matching measurements of a terrain profile with digital terrain map (DTM)
Underwater Navigation

- **Dead-Reckoning**
  - INS + DVL: state of the art for AUVs
  - Without external corrections, position estimates will drift and grow unbounded

- **Acoustic Navigation**
  - computation of ranges or bearings to acoustic beacons, with previously established and known positions
  - Provides external position corrections

- **TBN + Dead Reckoning**
  - allow AUVs to operate autonomously in highly unstructured environments
  - No need to resurface (GPS)
  - No need to deploy beacons
Description of the Algorithm

• Matching range measurements of the terrain against DTM
  – Correlation Methods
  – Bayesian Methods

• DTMs consist of gridded nodes
  – depths for a given position are computed by bilinear interpolation

• Simple generic model:
  – Position updates computed by INS: \( \mathbf{x}_{t+1} = \mathbf{x}_t + \mathbf{u}_t + \mathbf{v}_t \)
  – Nonlinear map function: \( \mathcal{H}(\mathbf{x}_t) \)
  – Process and Measurement noise: \( \mathbf{u}_t, \mathbf{w}_t \)
Altitude Estimation

• Multibeam Echosounder (MBE)
  – nearly optimal instruments for bathymetric terrain navigation
  – for low-altitude missions (<20m), the footprint of MBE becomes too small

• Side-scan sonar
  – wide swath even at low altitudes
  – Fairly good resolutions at a low processing cost

• DVL, Single Beam Sonar (altimeter)
  – more pings and more time will be needed in order to attain sufficient terrain data
  – DVL needs to be sufficiently close to the bottom
Correlation Methods

- Initial TBN methods were based on correlation
  - Seminal work for underwater based on TERCOM with a MBE
  - Correlation can be computed in different ways:

\[
COR(x_t) = \frac{1}{N} \sum_{i=1}^{N} (z_{t,i} - h_i(x_t))
\]

\[
ASD(x_t) = \sum_{i=1}^{N} (z_{t,i} - h_i(x_t))^2
\]

\[
MSD(x_t) = \frac{1}{N} \sum_{i=1}^{N} (z_{t,i} - h_i(x_t))^2
\]

- Batch estimation methods, needs several measurements
  - With a large enough number of measurements the TBN likelihood surface will collapse to a near-unimodal distribution
Correlation Methods (ii)

- Several modifications proposed to the original TERCOM
  - TERCOM is simple and reliable
  - real-time ability is reported to be poor and the navigation accuracy is low.

- Correlation + Kalman Filter to track the vehicle
  - Kalman Filter tracks the vehicle, correlation only on subparts of the map

- Correlation as input to the Kalman Filter
  - Position given by correlation is the measurement as seen by the KF

- Image-based correlation methods
  - Image-based correlation methods
  - When using sonars producing images from the bottom (e.g. Sidescan)
Bayesian Methods

- The Bayes formula is used to incorporate the measurement data into the estimation:

\[
p(x_t | z_t) = \frac{p(z_t | x_t)p(x_t | z_{t-1})}{p(z_t | z_{t-1})}
\]

- The TBN problem consists on solving for the posterior

- Due to the nonlinearity (DTM) these integrations are in general non-tractable an impossible to solve in closed form.
Bayesian Methods (ii)

• **Extended Kalman Filter (EKF)**
  – the state and process noise are mutually independent Gaussian
  – nonlinear measurement update approximated using a 1\textsuperscript{st} order Taylor expansion

• **Particle Filter (PF), Point Mass Filter (PMF)**
  – numerical approximation to the Bayesian filter.
  – large number of samples of the state vector to estimate its probability distribution
  – PF uses a dynamic stochastic state vector grid, PMF uses a deterministic state vector grid

  – The PMF is reported to be more robust and accurate, but is computationally more expensive.
Experimental Results

• A lot of different TBN approaches
  – Several methods proposed
  – Current trends focused on the use of Bayesian methods

• Not many experimental results presented so far.
  – Most use high-accuracy IMUs and sonars (MBE).
  – DTMAs with resolutions of around 10m
  – Position accuracies of few meters (<20m)

• Meduna presented (2011) interesting results using low-cost navigation sensors
  – DVL
  – Low grade IMU
Conclusion

• More accurate navigation in areas with greater bathymetric variability
  – Application for TRN are still limited by the need for an a-priori map

• Successful implementations of underwater TRN achieved high accuracy meter-level performance
  – Even with cheaper sonars and navigation sensors

• SLAM in unstructured environments is still an open question!