NEW PARADIGMS IN UNDERWATER MICRONAVIGATION

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OUTLINE

- SAS, PCA and DPCA review
- The vector space intersection based navigation error function
- Simulation results
- Performance with real data
A QUICK LOOK AT SAS
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ACOUSTIC MODEL

- Narrowband input

- Exploding source model
  \[ \alpha^2 \propto \delta(z_t, z) + \delta(z_r, z) \propto \tau(z_t, z_r, z) \]

- Output signal
  \[ r(t) = \int z \rho(z) \alpha(z_t, z_r, z, \vartheta_t, \vartheta_r) s(t - \tau(z_t, z_r, z)) \, dz \]

- Green's function
  \[ G(z_n) = \alpha(z_t, z_r, z_n, \vartheta_t, \vartheta_r) e^{-j2\pi f_0 \tau(z_t, z_r, z_n)} \]

- SISO model
  \[ \phi(t_m) = A(t_m, z_n) G(z_n) \rho(z_n) \]
> By the outputs of properly spaced SISO systems on a straight path, the reflectivity can be recovered with constant range resolution.

\[ \rho(z_n) \approx \sum_{l \in \mathbb{Z}} G_l^*(z_n) A_l^\dagger(z_n, t_m) \phi_l(t_m) \]  

**BACKPROJECTION**

> Design example

\[
D = 5 \text{ cm} \quad R = 150 \text{ m} \\
v \leq \frac{D}{4 \max(\tau(z_l, t, z_l, r, z_n))} \\
v = 6.25 \text{ cm/sec}
\]
ISSUES IN SAS

> The motion speed is limited by the desired cross range resolution and maximum range

> The coherent summation of pings requires an accurate knowledge of ping positions

> Vehicles have to be equipped with an Inertial Navigation System (INS)

> Further corrections are implemented by digital signal processing
PCA • PHASE CENTER APPROXIMATION
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DPCA • DISPLACED PHASE CENTER ANTENNA
Some of the PCA equivalent monostatic positions are shared between successive pings. The INS has to guarantee that the along track speed is constant, i.e. no longitudinal perturbation (surge). Rotation (yaw) and lateral perturbation (sway) are estimated by performing correlations between corresponding locations.
NAVIGATION MOTIONS

Range

Cross range

Surge

Sway

Yaw
MOTION ESTIMATION WITH DPCA
GOALS

Is it possible to extract all the motion information from raw data and give up to the INS?

Is it possible to measure the amount of coherence among pings contributing to the synthetic aperture?
MOTION ESTIMATION IN THE IMAGE SPACE

INT A = INT B

IMAGE FROM PING A

IMAGE FROM PING B

INTERSECTION OPERATOR

INT A ≠ INT B

IMAGE FROM PING A

IMAGE FROM PING B
MOTION ESTIMATION IN THE IMAGE SPACE

METHOD

> Estimate Tx to Rx rotation?

> Estimate the ping to ping displacement with no priors by projecting on the algebraic intersection between the corresponding subspaces

OUTCOMES

> Surge, sway and yaw are estimated at the same time

> An accurate INS is not necessary

> The trajectory can be non straight
Ping to Ping Displacement

- Consider the orthogonal projector at each ping
- Consider the projection on the intersection of the subspaces corresponding to two pings
- Compute the intersection with respect to the two pings as a function of the hypothetical displacement

\[ Q^{(p)} = (\tilde{T}^{(p)})^{-1} \tilde{T}^{(p)} \]
\[ \psi = \lim_{i \to \infty} (Q^{(q)} Q^{(p)})^i \rho \]
\[ \psi^{(p)}_{\mu, \nu, \xi} = \lim_{i \to \infty} (Q^{(p)} S^{\mu, \nu, \xi}[Q^{(p)}])^i \rho^{(p)} \]
\[ \psi^{(q)}_{\mu, \nu, \xi} = \lim_{i \to \infty} (S^{\mu, \nu, \xi}[Q^{(p)}] Q^{(p)})^i \rho^{(q)} \]
Employ an error function based on amplitude for rough estimation and an error function based on phase for fine estimation.
THE EXPERIMENT

EXPERIMENTAL SETUP

> start and stop acquisition
> subwavelength ground truth not available
> no yaw

THE TARGET

> 4 point reflectors
> in the close range
EXPERIMENTAL RESULTS

- N-1 superimposed phase centers
- Various trajectories obtained by subsampling

The unknown initial rotation causes an apparent backward drift.
EXPERIMENTAL RESULTS: imaging

SISO - no error compensation

SISO - with error compensation

EXPERIMENTAL RESULTS: imaging
EXPERIMENTAL RESULTS: imaging

SIMO - no error compensation

SIMO - with error compensation
An accurate motion estimation procedure has been identified

The computational cost is remarkable but less prior information is required

The procedure has been validated on real data
THANKS FOR YOUR ATTENTION