NEW PARADIGMS IN UNDERWATER MICRONAVIGATION

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Heriot-Watt University

Underwater Sensing, Signal Processing and Communications

UDRC themed meeting · NEWCASTLE

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OUTLINE

> SAS, PCA and DPCA review

> The vector space intersection based navigation error function

> Simulation results

> Performance with real data

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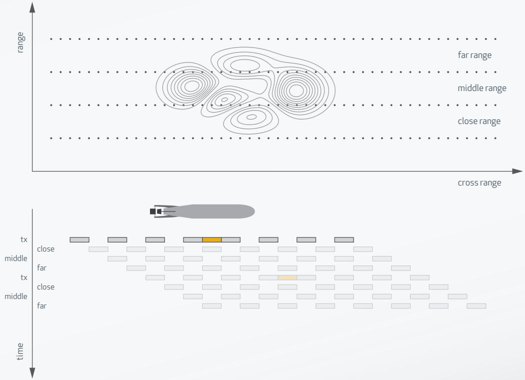
A QUICK LOOK AT SAS



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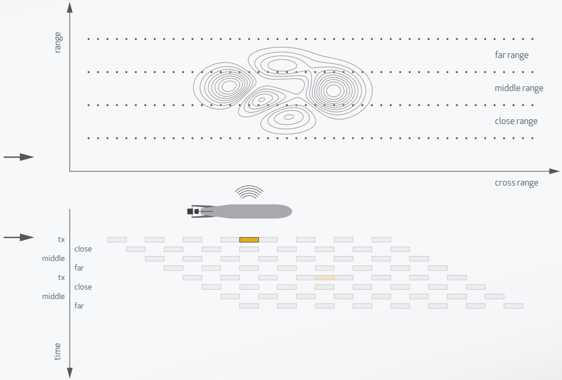
A QUICK LOOK AT SAS



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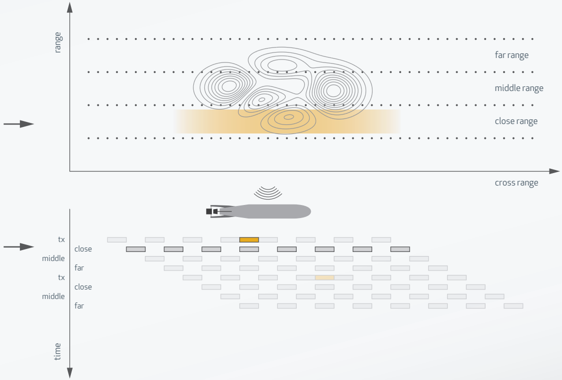

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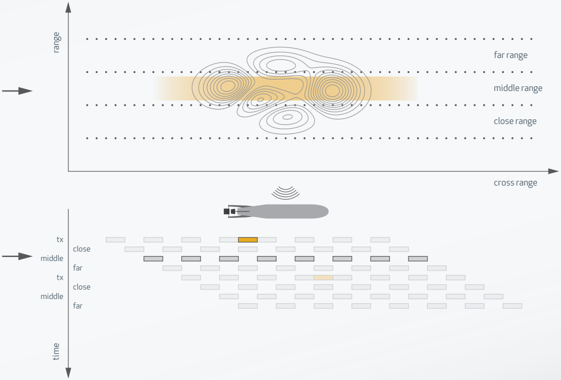

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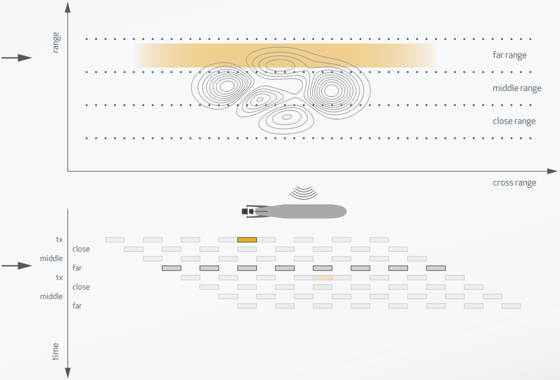

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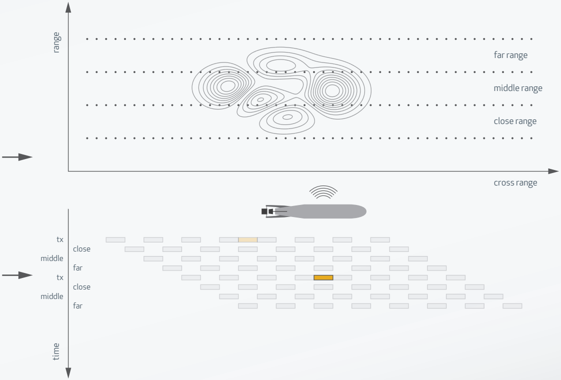

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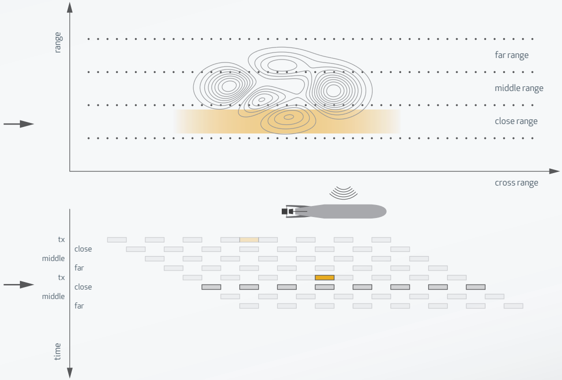

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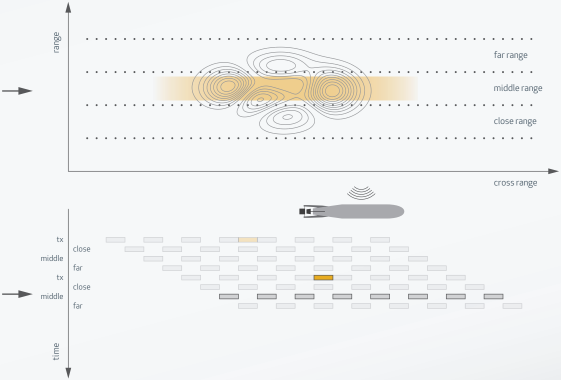

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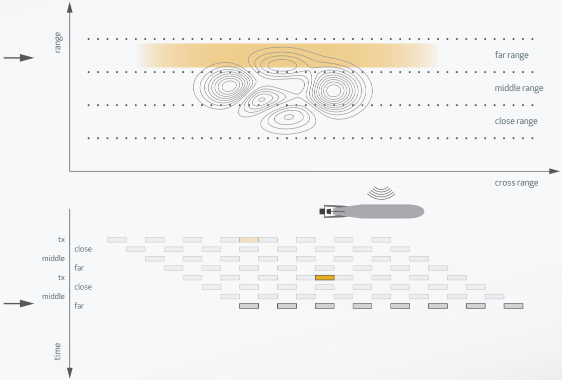

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ACOUSTIC MODEL

> 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

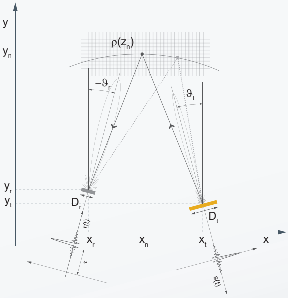
$$r(t) = \int_z \rho(z)\,\alpha(z_t, z_r, z, \vartheta_t, \vartheta_r)\,s(t - \tau(z_t, z_r, z))\,\mathrm{d}z$$

> 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

$$\phi(t_m) = A(t_m, z_n)\,G(z_n)\rho(z_n)$$



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SAS IMAGING

> 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

$$D = 5\,\mathrm{cm} \qquad R = 150\,\mathrm{m}$$

$$v \leq {}^{D}\!/\!_{4 \max(\tau(z_{l,t}, z_{l,r}, z_n))}$$

$$v = 6.25\,\mathrm{cm/sec}$$

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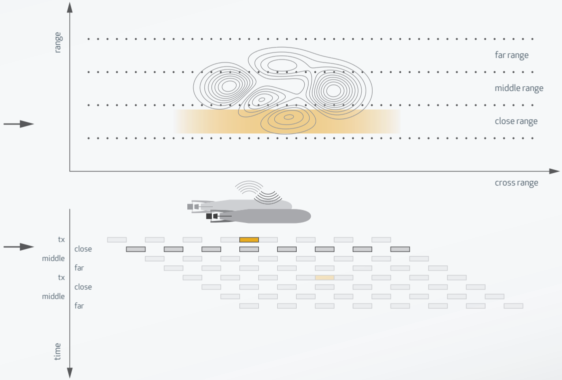
ISSUES IN SAS

- 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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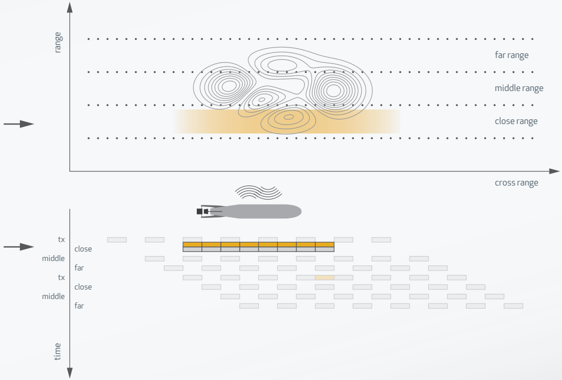

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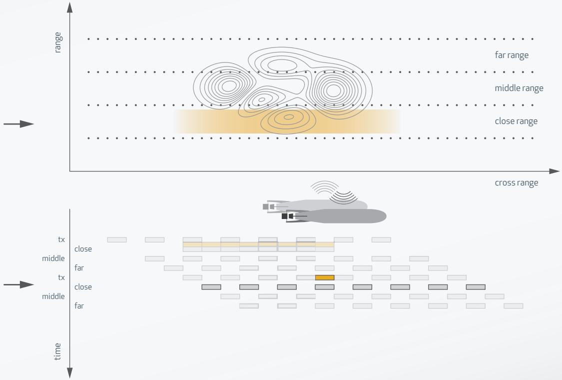

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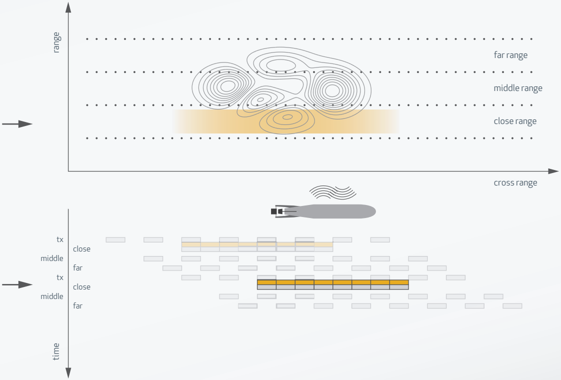
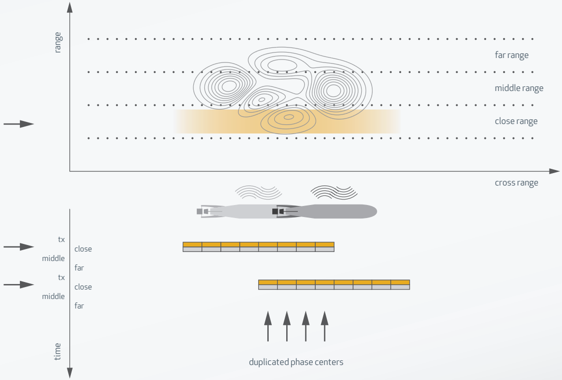


DPCA • DISPLACED PHASE CENTER ANTENNA



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DISPLACED PHACE CENTER ANTENNA

> Displaced Phase Center Antenna is the state of art technique for estimating the perturbations between two pings

> 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

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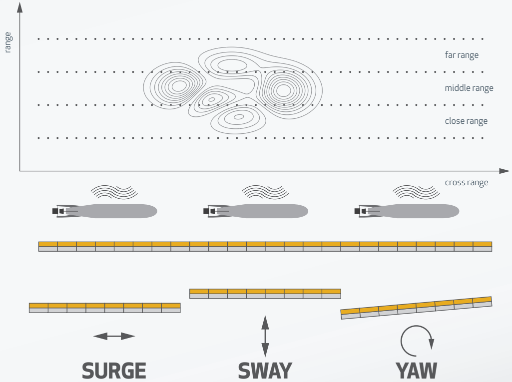
NAVIGATION MOTIONS



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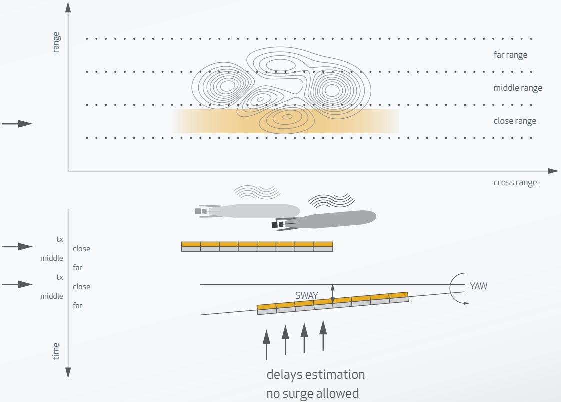
MOTION ESTIMATION WITH DPCA



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?

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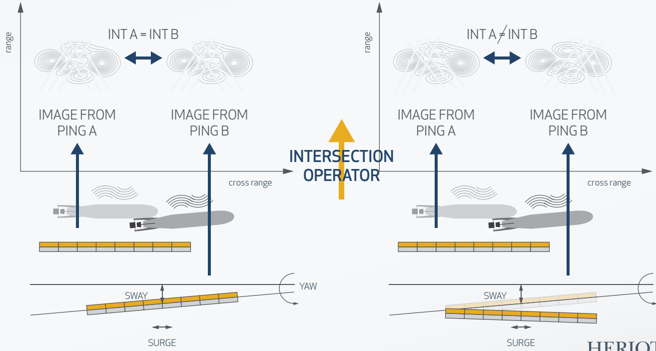
MOTION ESTIMATION IN THE IMAGE SPACE



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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

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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

$$Q^{(p)} = (\tilde{T}^{(p)})^{-1}\tilde{T}^{(p)}$$

$$\psi = \lim_{i\to\infty}(Q^{(q)}Q^{(p)})^i\rho$$

$$\psi^{(p)}_{\tilde{\mu},\tilde{\nu},\tilde{\xi}} = \lim_{i\to\infty}(Q^{(p)}S_{\tilde{\mu},\tilde{\nu},\tilde{\xi}}[Q^{(p)}])^i\breve{\rho}^{(p)}$$

$$\psi^{(q)}_{\tilde{\mu},\tilde{\nu},\tilde{\xi}} = \lim_{i\to\infty}(S_{\tilde{\mu},\tilde{\nu},\tilde{\xi}}[Q^{(p)}]Q^{(p)})^i\breve{\rho}^{(q)}$$

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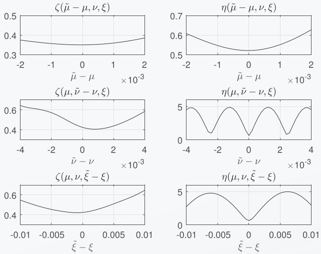
PING TO PING DISPLACEMENT

- Employ an error function based on amplitude for rough estimation and and error function based on phase for fine estimation



SURGE

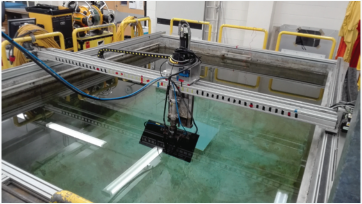
SWAY

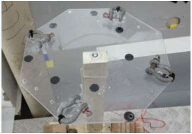
YAW

THE EXPERIMENT

EXPERIMENTAL SETUP

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





THE TARGET

- 4 point reflectors
- in the close range

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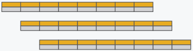
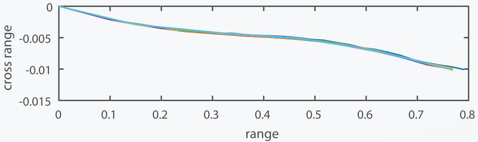
EXPERIMENTAL RESULTS

> N-1 superimposed phase centers

> various trajectories obtained by subsampling





the unknown initial rotation causes an apparent backward drift

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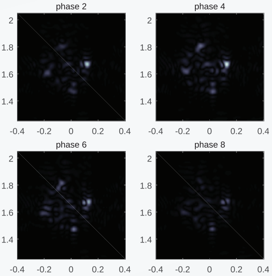
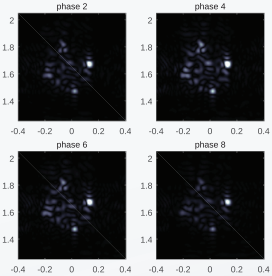
EXPERIMENTAL RESULTS: imaging

SISO - no error compensation



SISO - with error compensation



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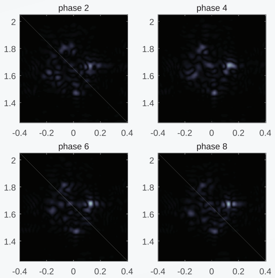
EXPERIMENTAL RESULTS: imaging

SIMO - no error compensation



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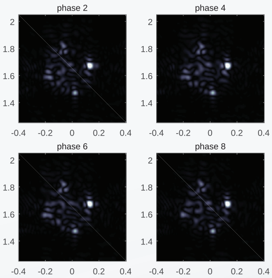

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CONCLUSION

- 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