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Evaluation of a Canonical Image Representation for Sidescan Sonar (SSS)

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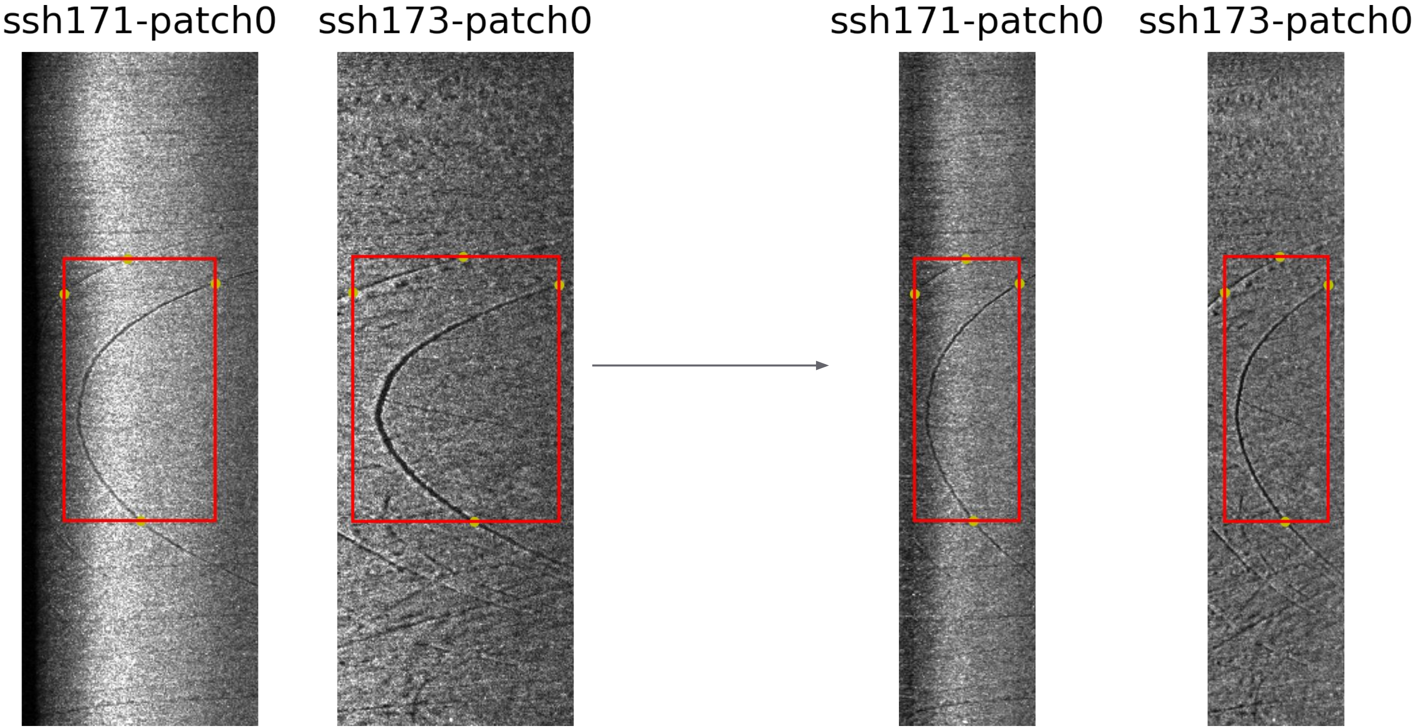
Paper summary



Raw SSS patches of the same physical area

Canonical SSS patches

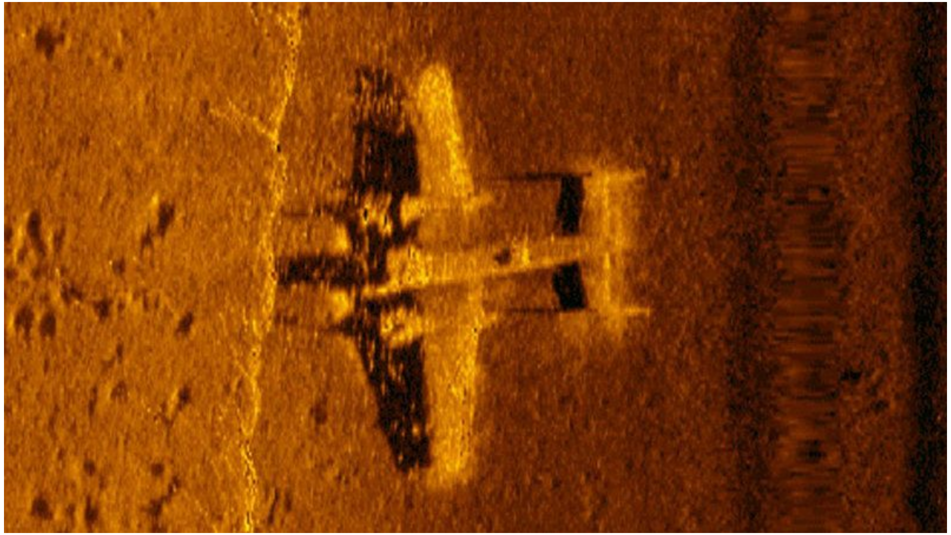
Outline

- Motivation
  - Sidescan sonar (SSS) for underwater SLAM
- Method
  - Constructing SSS “images” from sonar echos
  - A typical SSS canonical transformation procedure
  - Details of our methods
- Experiments
  - Data preparation
  - Qualitative results
  - Quantitative metrics & results
- Conclusions & future work

Sidescan Sonar (SSS) for Underwater SLAM

- Pros:
  - High resolution
  - Photorealistic “images”
  - Long-range measurements
  - Relatively cheap

- Challenges:
  - Geometric distortions
  - Intensity distortions



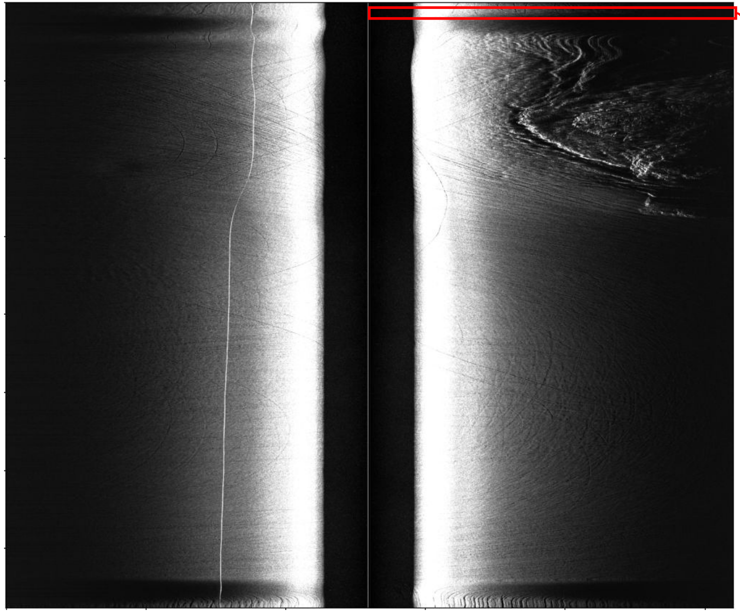
High resolution SSS image of a WWII B-25*

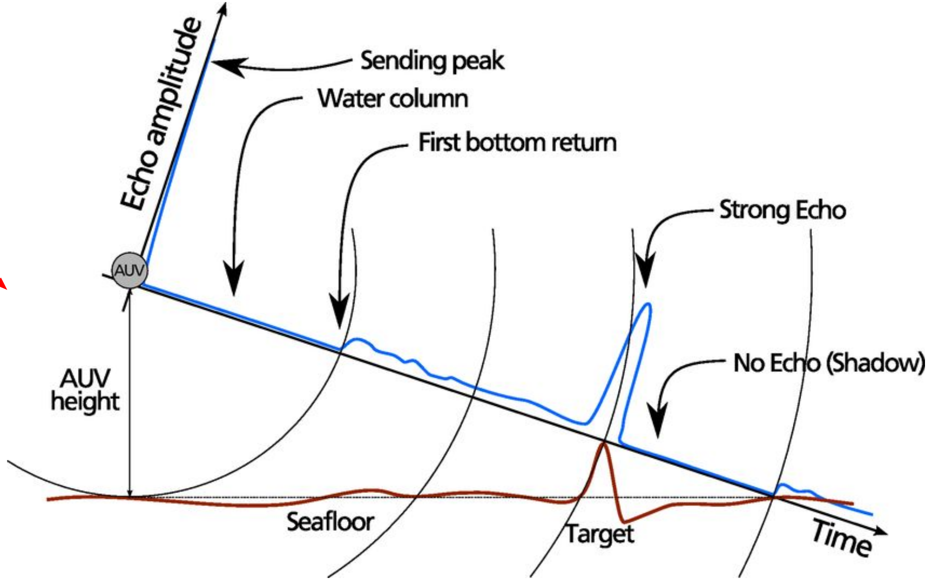
* Image source: National Oceanic and Atmospheric Administration (NOAA)

Constructing SSS “Images”

port

starboard





Canonical Transformation of SSS Images

- General pipeline:
  - Intensity correction
  - Slant-range correction
- Our contributions:
  - For intensity correction: three relationships *cos*, cos^2, *cot*
  - For slant-range correction: sensor *independent* correction
  - Evaluate SSS canonical transformation on real data

Step 1 - Intensity Correction

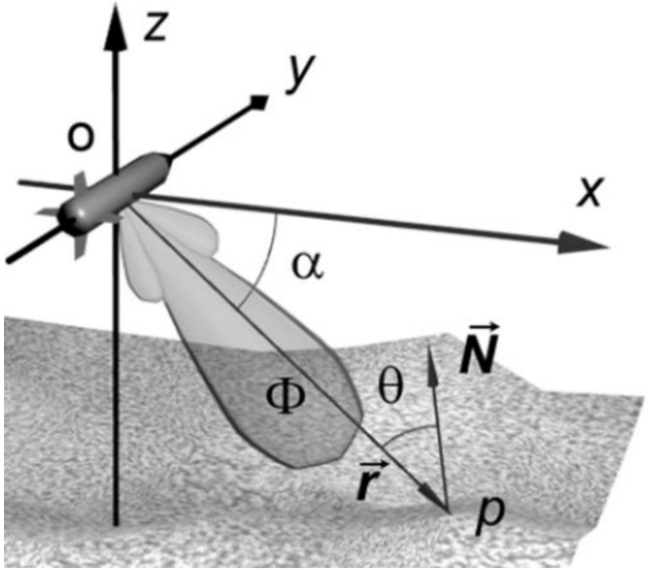
- Goal:
  - A perfectly flat seafloor should return uniform intensity
- Lambertian model:

$$I(p) = K\Phi(p)R(p)|\boxed{\cos}(\theta(p))|$$

(cos, cos², cot)

- Intensity correction:

$$\tilde{I}(p) = \frac{I(p)\sec(\theta(p))}{\Phi(\phi(p))}$$



Step 2 - Sensor Independent Slant Range Correction

- Goal:
  - Each bin/pixel represents the same ground range instead of slant range

- Method:
  - Project all sonar intensities to the assumed flat seafloor
  - Weighted sum interpolation of original intensities:

$$\bar{I}_i = \sum_j w_{ij} \tilde{I}_j$$

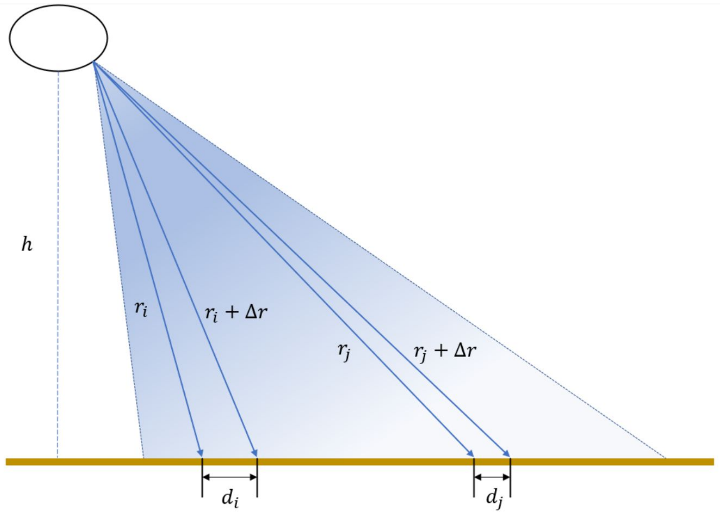


Fig. 2: An intuitive comparison of ground range bin sizes at different slant ranges. With the same slant range resolution Δr, the effective ground range resolution increases as we move away from the sonar head.

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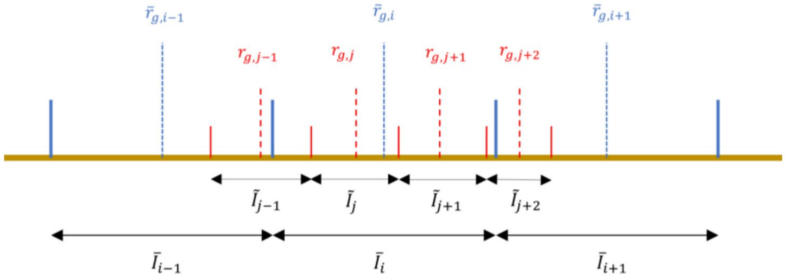
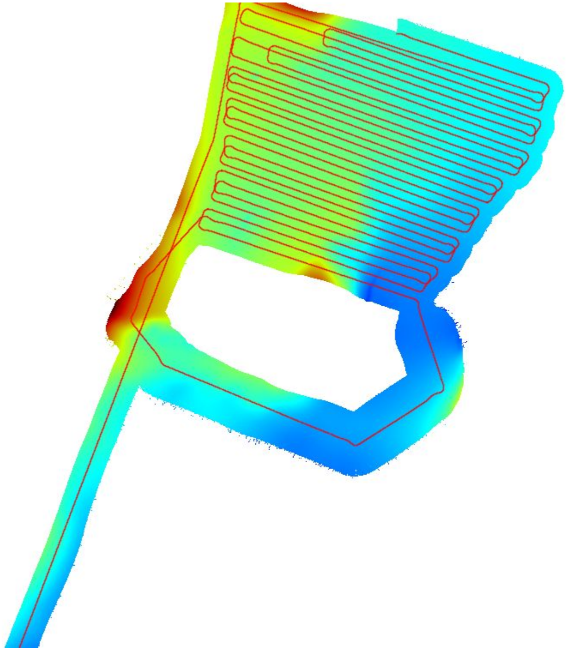


Fig. 3: Interpolation in uniform ground range. The red solid vertical lines are the original points where the sidescan bin range hits the horizontal seafloor and the red dashed lines are the midpoints. The blue solid vertical lines are the evenly spaced ground range points and the blue dashed vertical lines are the midpoints [24].

Experiments: Data Preparation

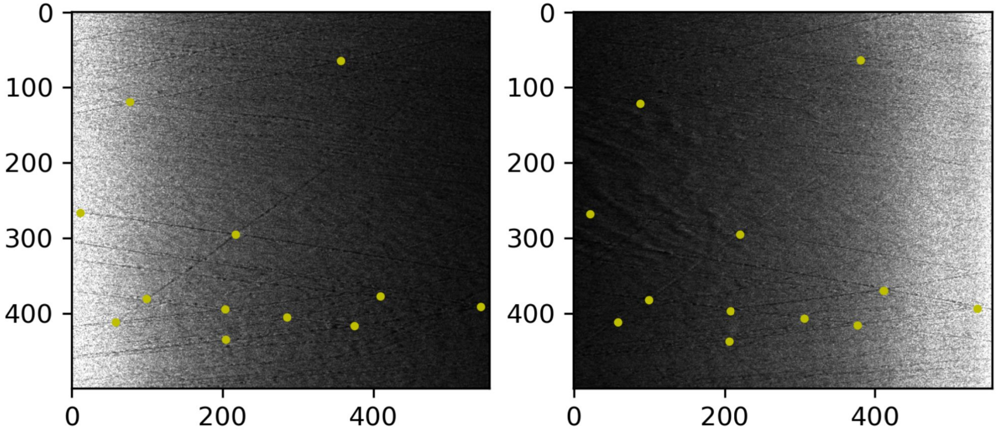
- Data collection with Kongsberg's Hugin AUV with EM2040 MBES and Edgetech 2205 SSS
- MBES data used for *ground-truthing* and *evaluation*:
  - MBES data -> mesh -> drape SSS onto onto mesh to obtain 3D positions per bin
  - Manually select keypoints in SSS images, use 3D position to retrieve corresponding keypoint locations in SSS images from other survey lines
  - -> corresponding patch pairs from different SSS images around keypoints we've selected



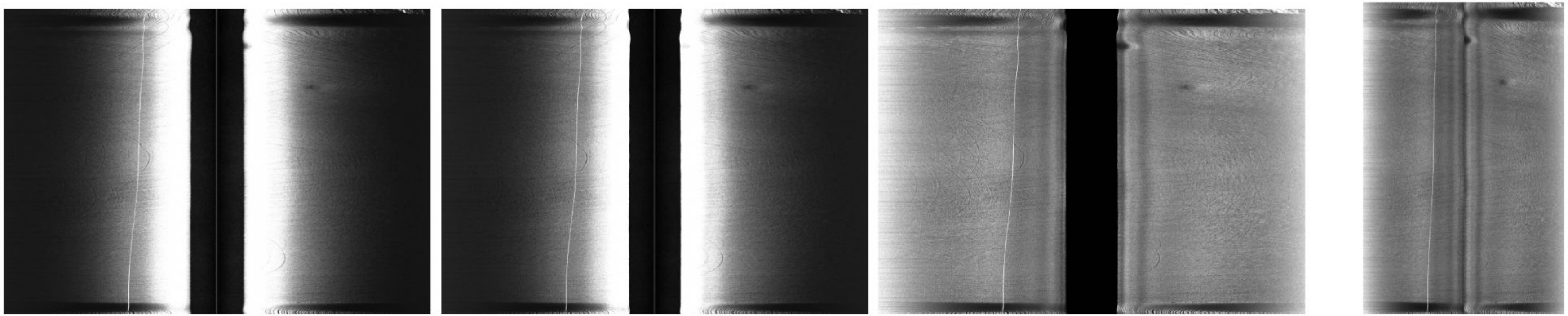
Mesh built from MBES data of this survey and AUV's trajectory

Experiments: Data Preparation

- Dataset size:
  - 13208 pings
  - 1270 keypoints
  - 60 patch pairs
- Example patch pair from 2 different survey lines:



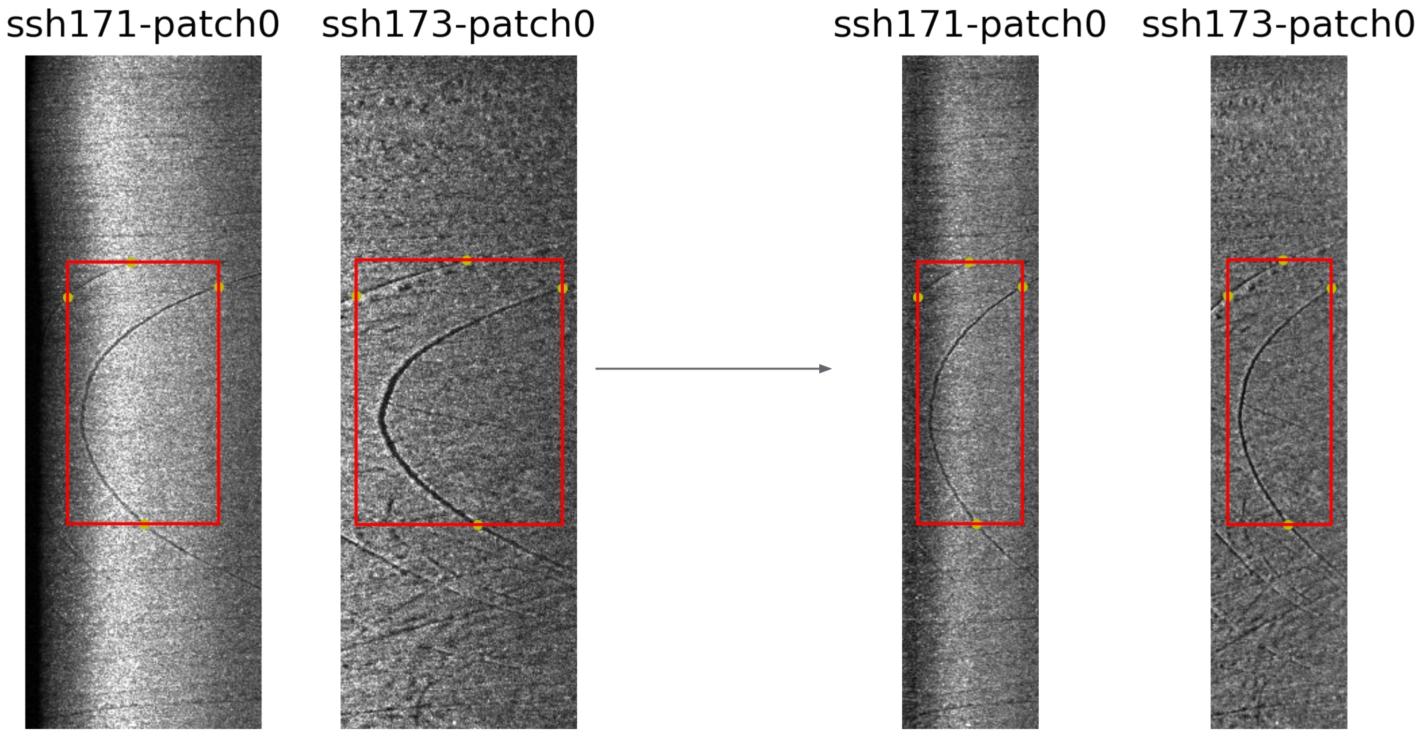
Experiments: Qualitative Results



(a) Raw (b) Beam pattern correction (c) Incidence angle correction (d) Slant range correction

Fig. 5: Comparison of a SSS waterfall image after each of the proposed transformation steps using $\cos^2$ law. (a)-(d) corresponds to the output after each step of the transformation, where (a) is the raw image, (b) is the beam pattern correction result, (c) is the incidence angle correction result and (d) is the slant range correction result, which is also the final output the proposed canonical transformation. The black strip in the center of (a)-(c) is the *nadir zone* with low backscatter intensity and represents the distances where no seafloor is detected by the SSS. This region is removed in (d).

Experiments: Qualitative Results



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Canonical SSS patches

Experiments: Quantitative Evaluation Metrics

- Patch similarity measures:
  - Correlation:

$$R(F,G) = \frac{\sum_{x,y} \left(F\left(x,y\right) \cdot G\left(x,y\right) \right)}{\sqrt{\sum_{x,y} F\left(x,y\right)^2 \cdot \sum_{x,y} G\left(x,y\right)^2}}$$

TABLE I: Results in correlation measure for raw and canonical dataset. The highest values are highlighted in **bold**.

Method	Proportion of Improved patches	Average Similarity	Average Improvement
None	–	0.6905	–
cos	98.33%	0.8810	27.59%
$\cos^2$	98.33%	**0.9287**	**34.50%**
cot	98.33%	0.8988	30.17%

  - Other metrics: Chi-square; KL divergence (see paper)

Experiments: Quantitative Results

- Descriptor matching results using ORB and SIFT:

TABLE III: Matching results of ORB and SIFT descriptors for raw and canonical transformation. The best values for each distance metric are highlighted in **bold**.

Descriptors	Method	Total Matches	Correct Matches	Accuracy
SIFT	None	153	133	86.93%
	cos	160	146	91.25%
	$\cos^2$	164	**152**	**92.68%**
	cot	168	151	89.88%
ORB	None	75	50	66.67%
	cos	87	**55**	63.22%
	$\cos^2$	76	54	**71.05%**
	cot	85	**55**	64.71%

Conclusion

- We proposed some enhancement to existing SSS canonical representation methods
- Performed qualitative and quantitative evaluation on real SSS data
- Cos^2 achieves highest patch similarity and SIFT matching scores
- But…
  - Data size is very limited
- Future work:
  - Remove flat seafloor assumption
  - *Integrate canonical representation into SLAM framework*

Actually some future work!

Check out our
SSS-SLAM paper
on ArXiv!