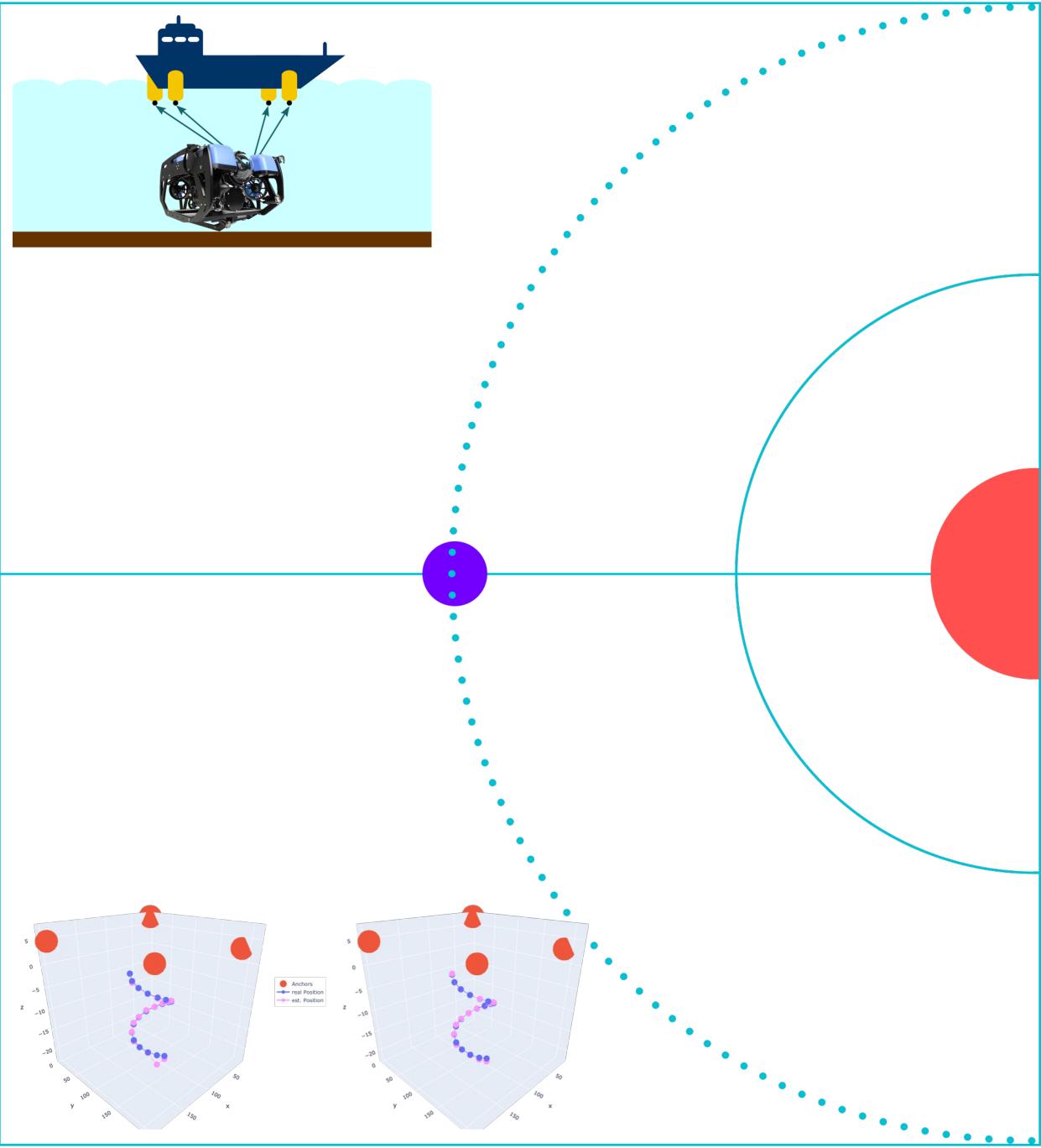
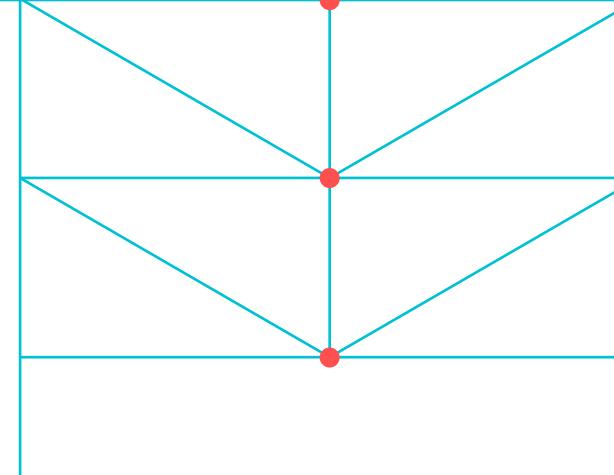


Orthogonal Codes for Acoustic Underwater Localization

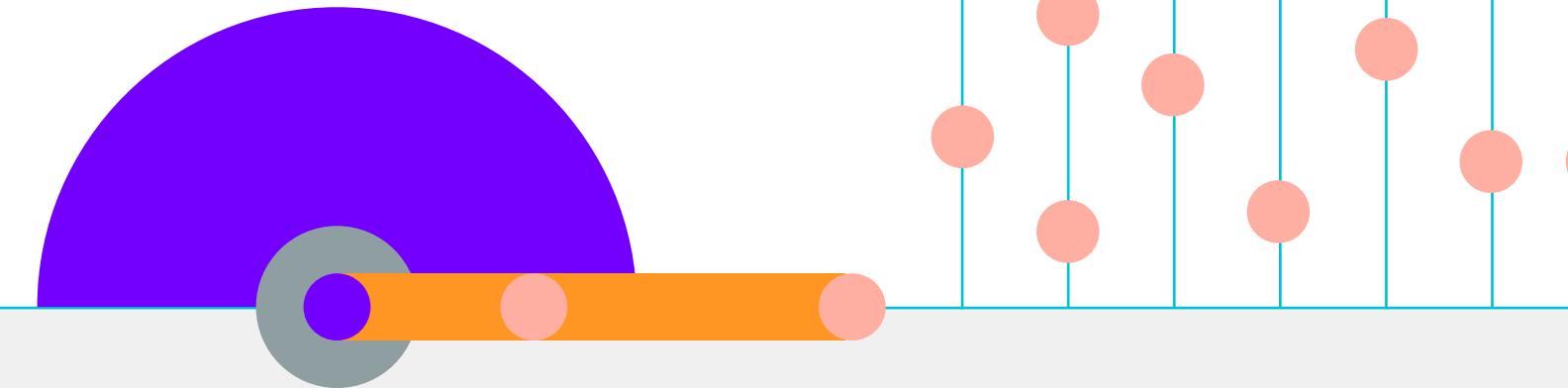
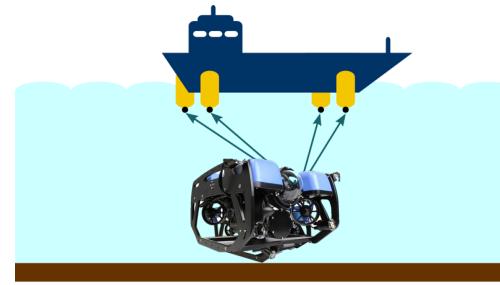
TUHH
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Hamburg

Sergej Keller



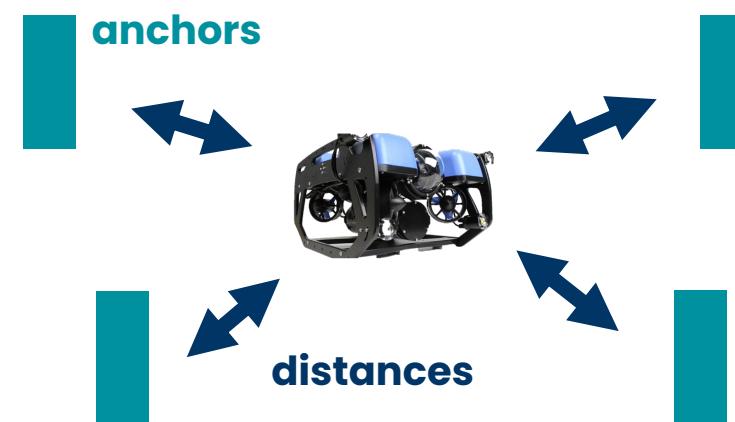
Content

- I. Motivation
- II. Concept
- III. Codes
- IV. Signal processing
- V. Localization
- VI. Results
- VII. Conclusion



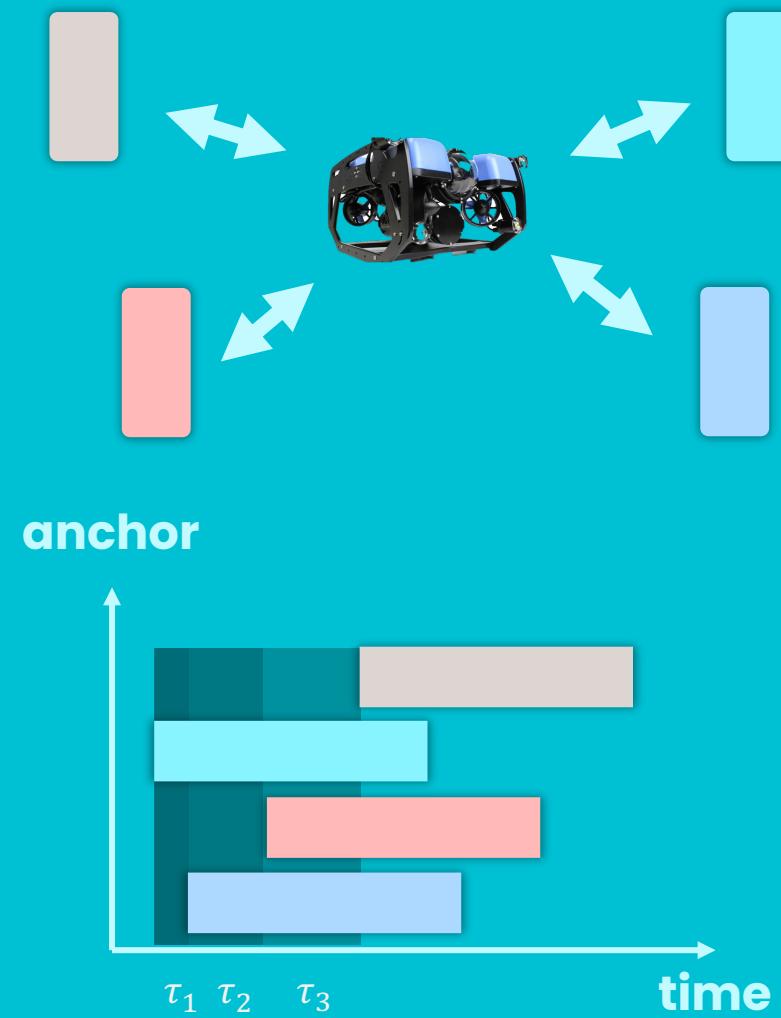
Motivation

- Acoustic transmission
 - Underwater communication
 - Electromagnetic waves not applicable
- Autonomous diving, underwater navigation
 - Self-localization
 - Reverse method of classic approach

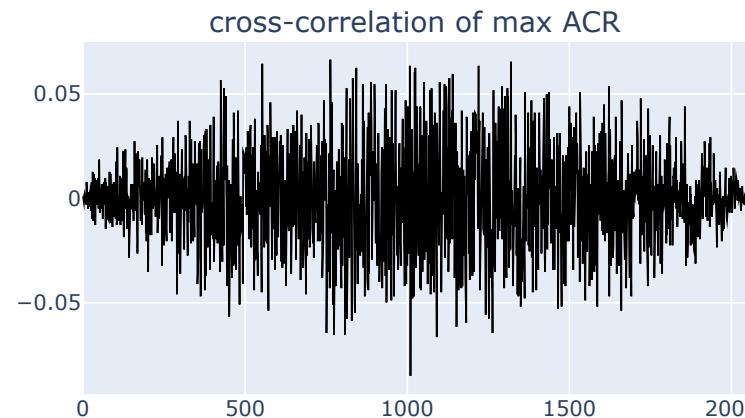
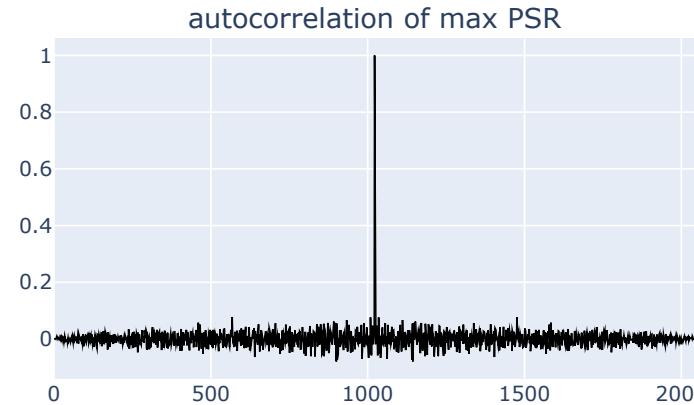


Concept

- Acoustic signals
 - Send synchronized by hydrophones
 - Challenges like multipath propagation & noise
- Time Difference of Arrival (TDOA)
 - Correlation technique to estimate position
 - Works great with orthogonal codes
- Orthogonal codes
 - Separable signals
 - Already in use in telecommunications



Orthogonal PN codes – introduction



Code properties

- Auto-correlation properties
→ improved peaks in correlation
- Cross-correlation
→ better separability, less cross talking

Code and signal length

Code length N, signal length M

$$N = 2^d - 1$$

$$M = \frac{N}{f_s}, [M] = s$$

$$f_s = 20.000\text{Hz}, d \in \{8,9,10\}$$

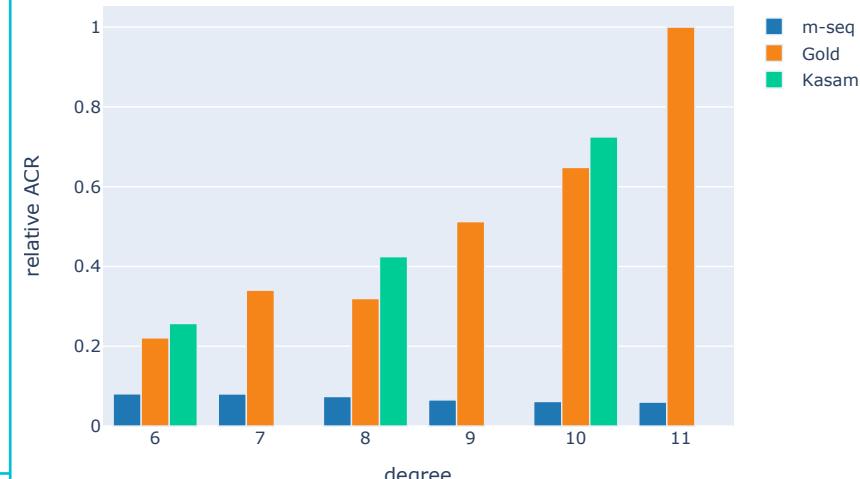
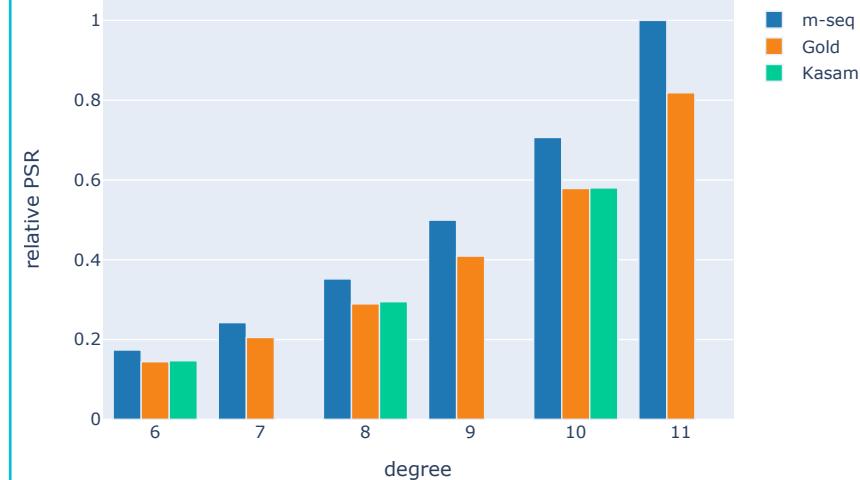
Orthogonal PN codes – evaluation results

Evaluation parameters

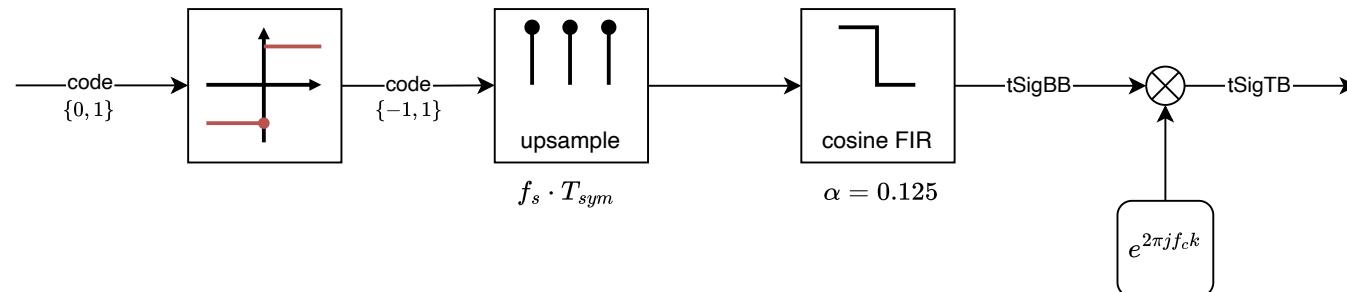
- Peak to Sidelobe Ratio (PSR)
→ increases with peak clarity
- Autocorrelation to Cross-correlation Ratio (ACR)
→ increases with code separability, orthogonality

Evaluation results

- M-sequences have worst separability
- Gold codes and Kasami codes are on the same level
- Gold codes chosen because of larger sets
→ scalability of anchors

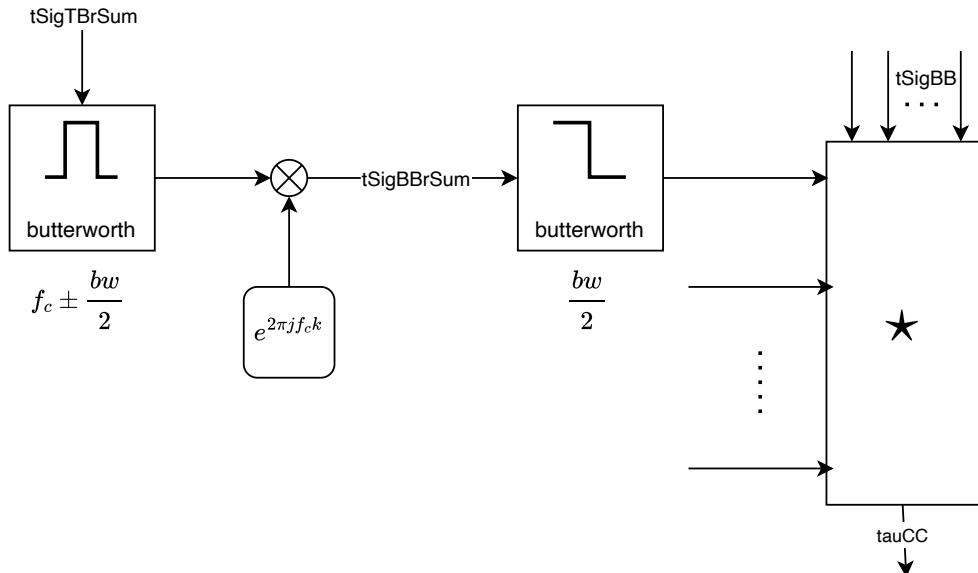


Signal processing – sending & receiving



Sending signal

- Binary code converted to signed
- up sampled & applied FIR filter
- Shifted to transfer-band for transmission



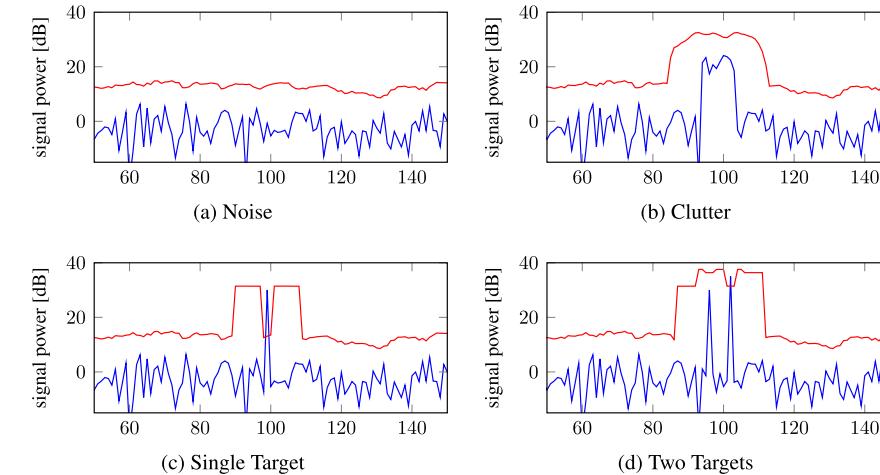
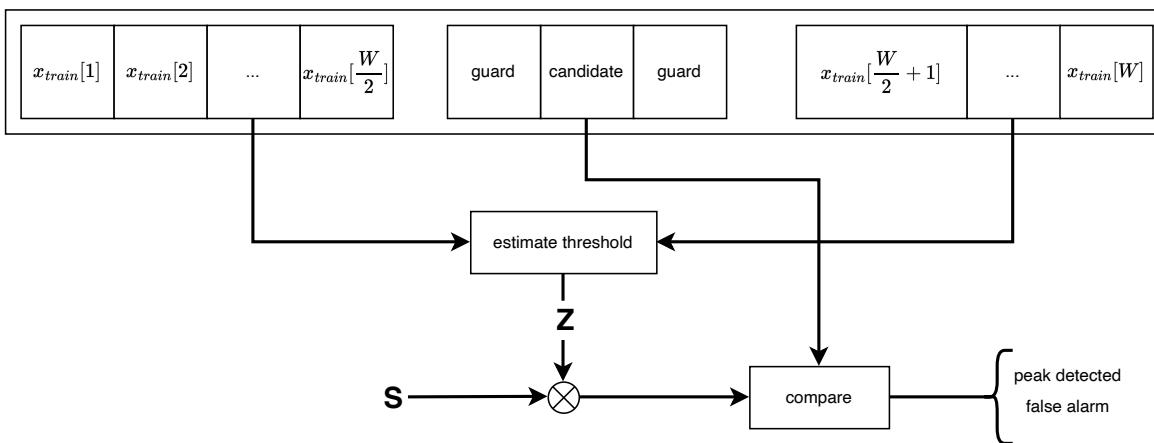
receiving signal

- Sum of signals filtered & back shifted to baseband
- Second filter removing shifting characteristics
- Cross correlation with original signals

Peak detection – CA-CFAR

Localization procedure

- **Cell Averaging – Constant False Alarm Rate**
- 2 bins: guard and train
 - Guard cells increases threshold around peaks
 - train cells get an estimate of the sidelobes
 - Scaled by factor S , the resulting threshold decides between peak or false alarm



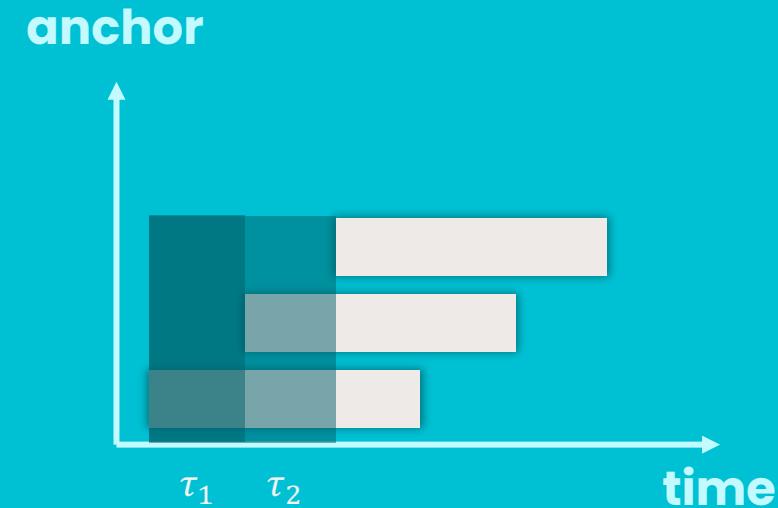
[Hermann Rohling. Ordered statistic cfar technique - an overview. In 2011 12th International Radar Symposium (IRS), page 635, 2011]

Alternative cell measure

- **Ordered Statistics – Constant False Alarm Rate**
- Using median instead of averaging
- Not used in project

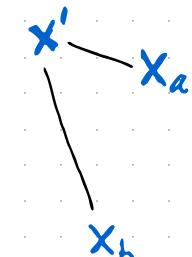
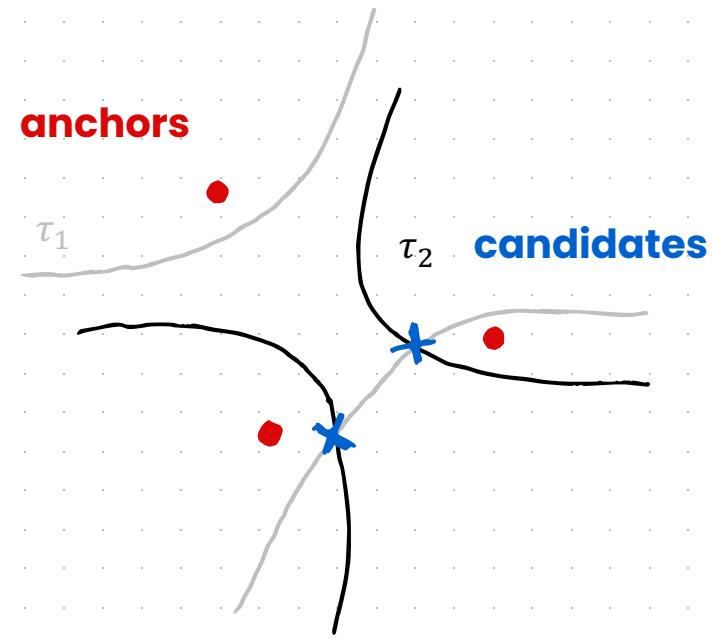
Localization algorithm

- hyperbolic position location technique by TDOA
- For N dimensions N+1 beacons needed



Localization algorithm

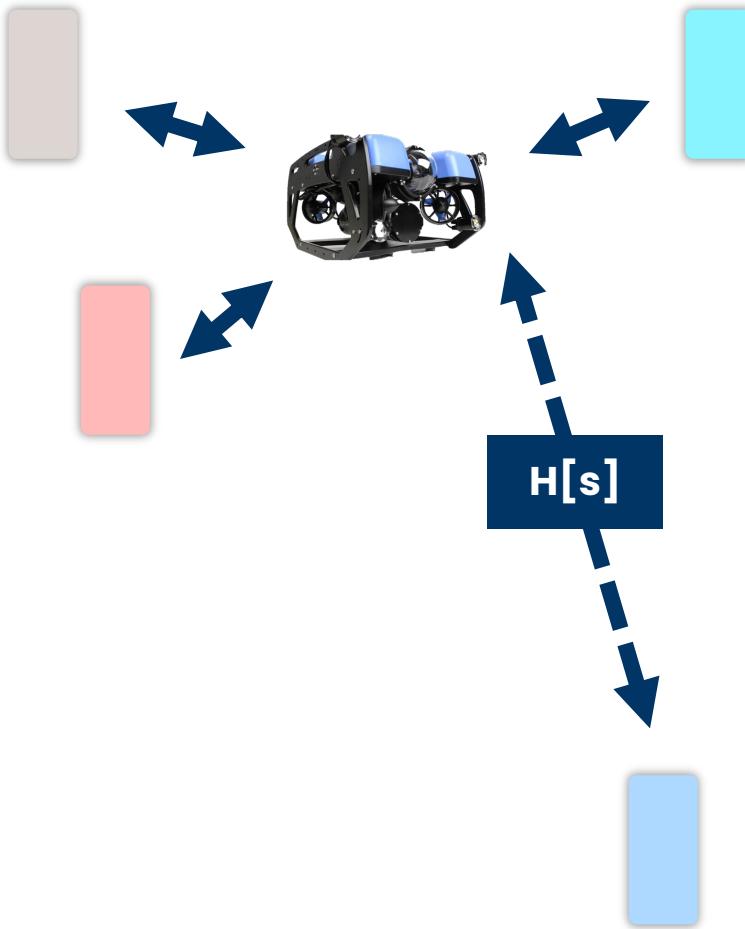
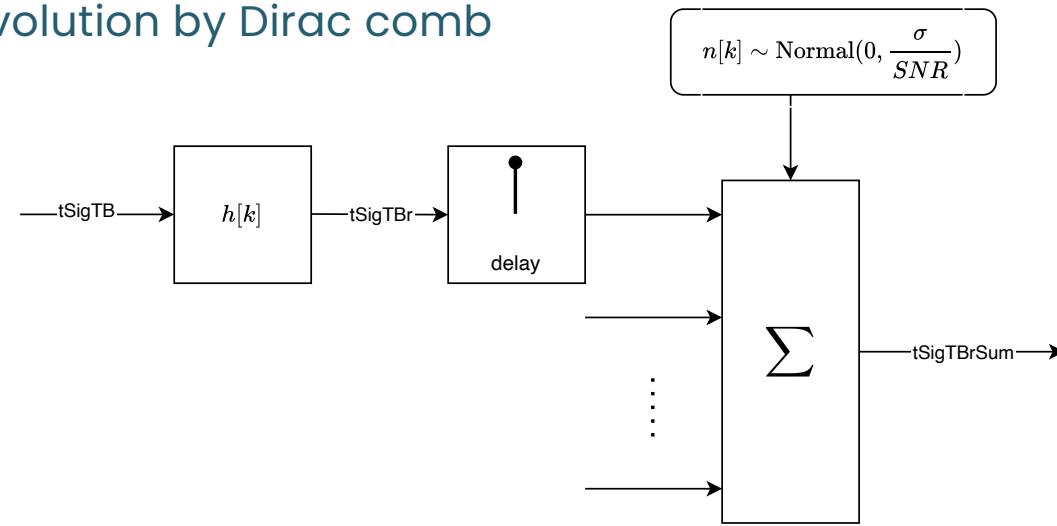
- hyperbolic position location technique by TDOA
- For N dimensions N+1 beacons needed
- Used in GPS
- Creates 2 candidates for position
- Candidate selection
 - Environmental information
 - Conclusions based on previous position



$$z = \begin{cases} z_a & \text{if } |z_a - z'| < |z_b - z'| \\ z_b & \text{else} \end{cases}$$

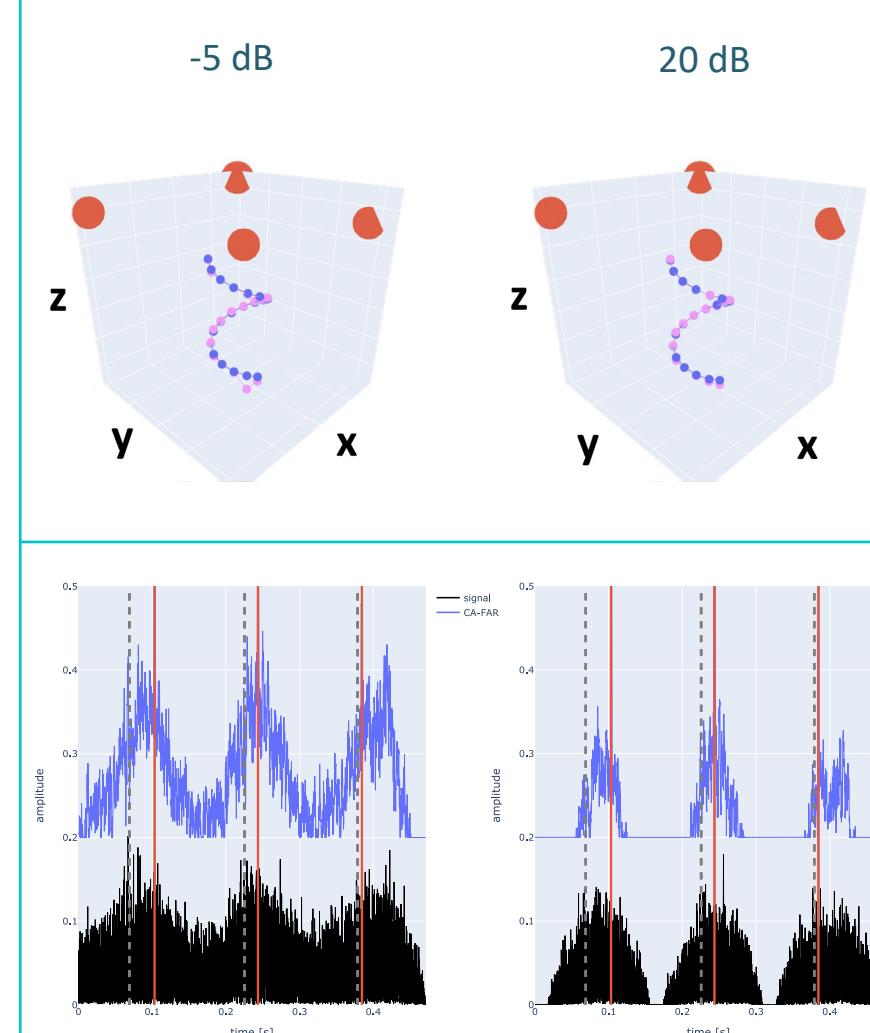
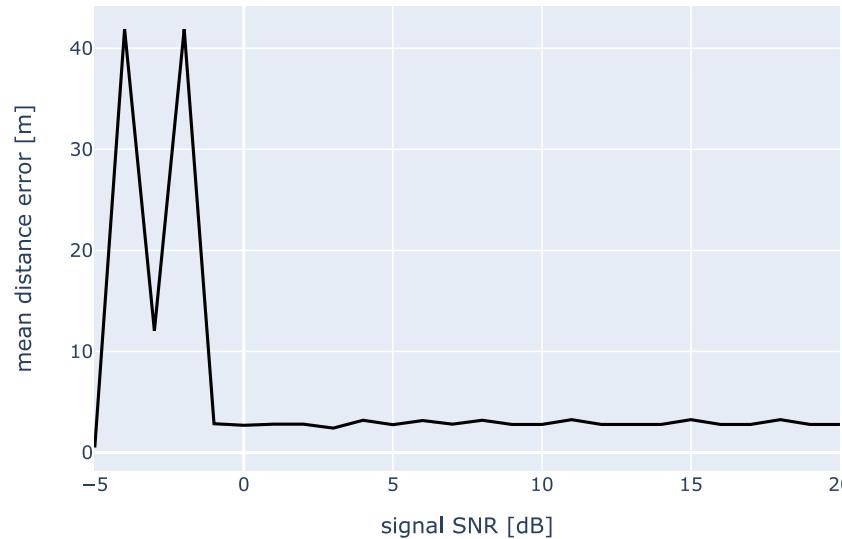
Simulation process

- Delays, calculated from example coordinates, add to signals
- Delayed signals get summed up
- To the sum a by SNR adjustable noise gets added
- Additional **Watermark simulation**
 - Uses different channels
 - Convolution by Dirac comb



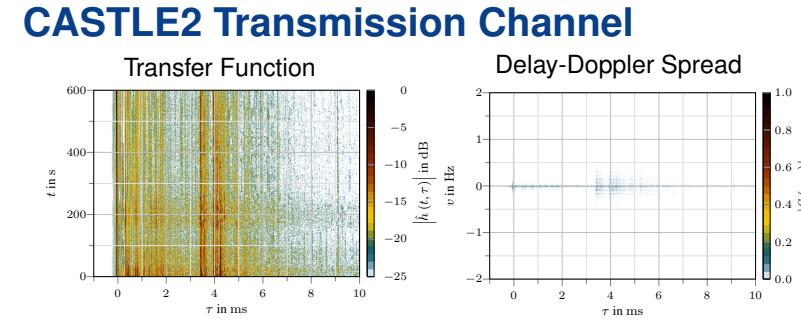
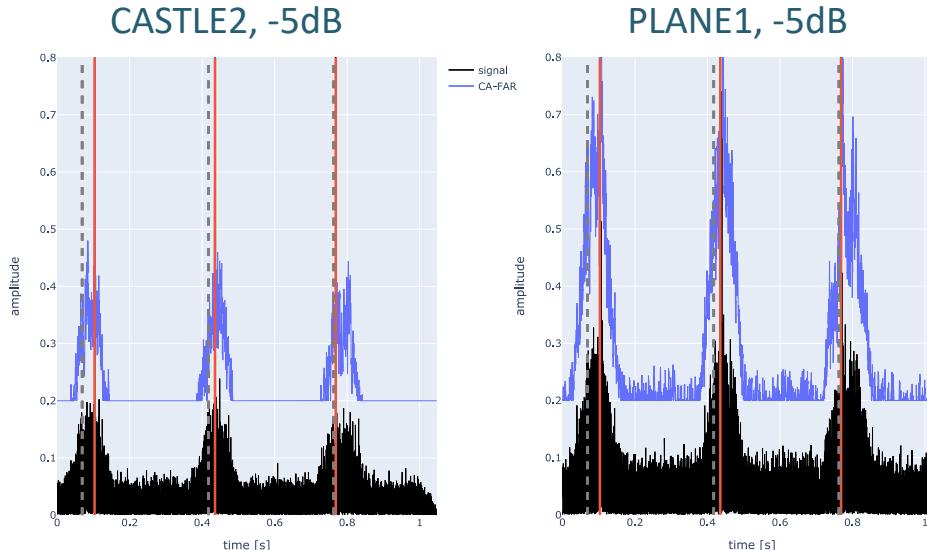
Simulation – results

- For simulation, a circular path & corresponding TDOA are generated
- 4 anchors placed above spanning a rectangular shape
- Different **levels of noise** and Watermark channels
PLANET and CASTLE2 used
- Increasing noise highly rise the risk of false detection of peaks and therefore unreliable position data

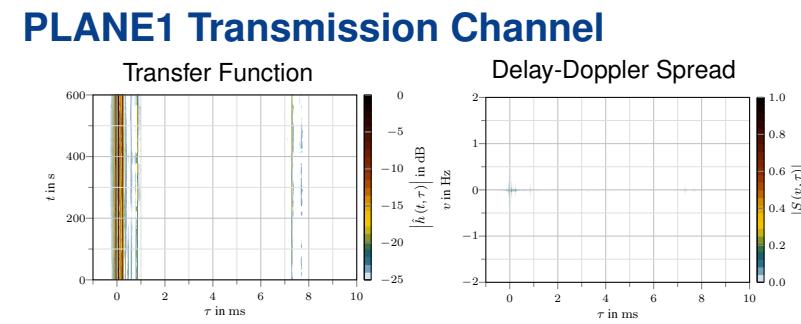


Simulation – results

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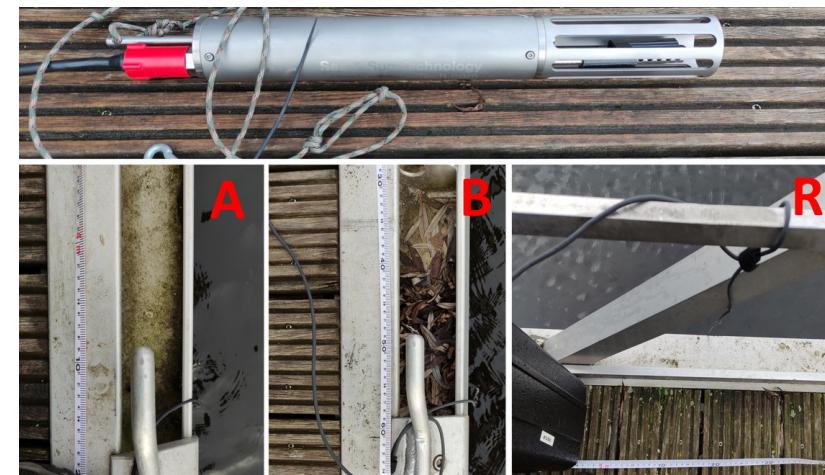
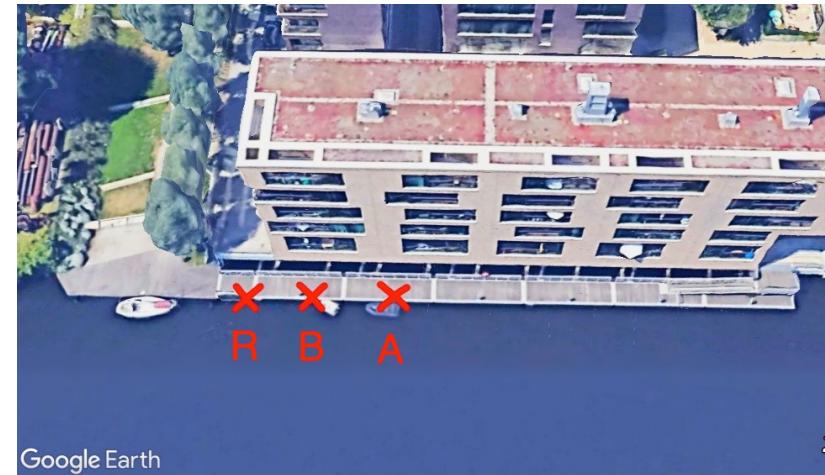
[P. van Walree, R. Otnes, and T. Jenserud, Watermark: A realistic benchmark for underwater acoustic modems, in 2016 IEEE Third Underwater Communications and Networking Conference (UComms), Aug 2016]



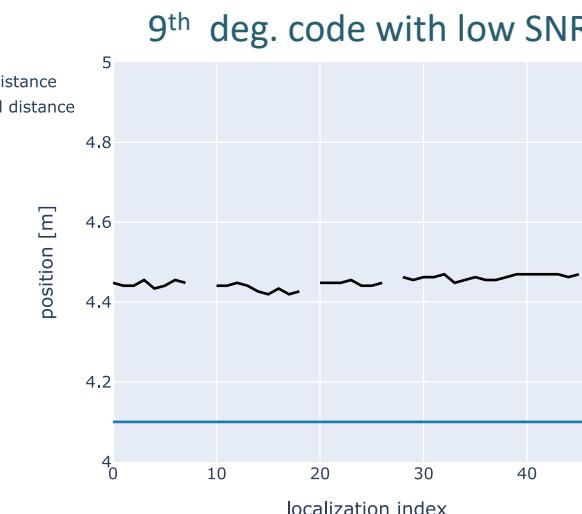
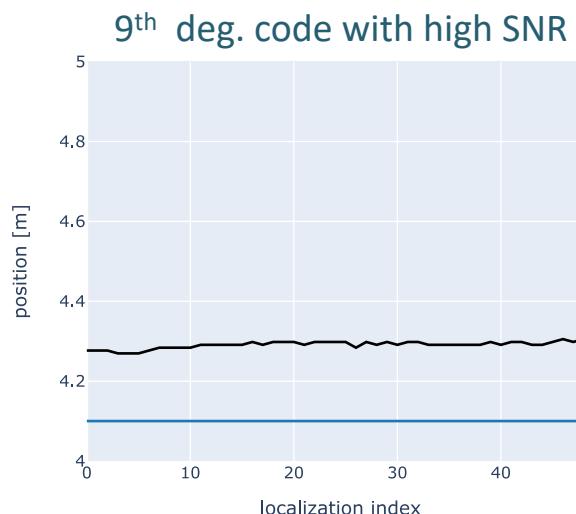
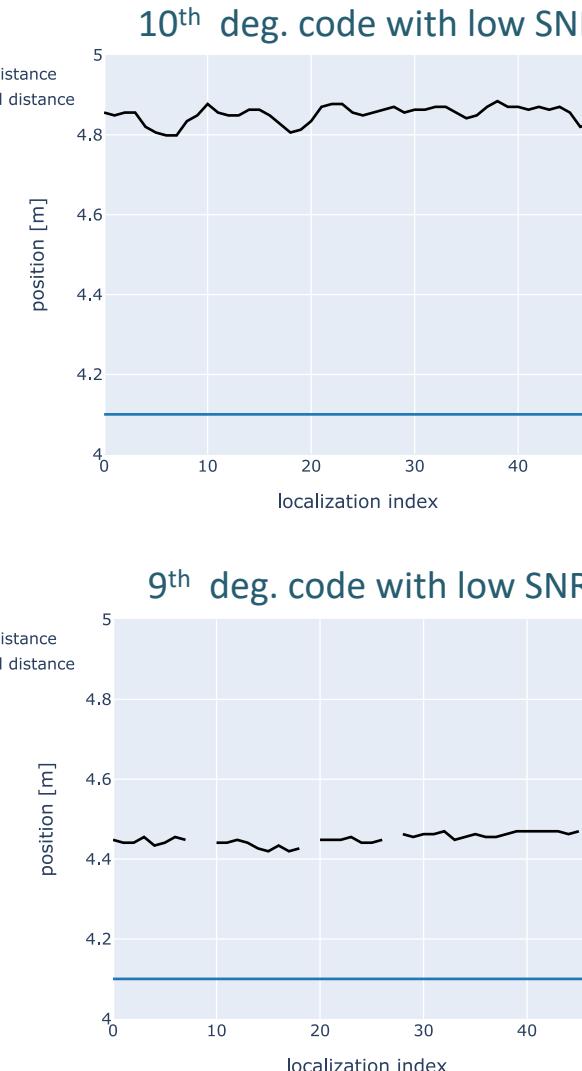
Real world setup

- Field test at shoreline location with 3 hydrophones deployed at 1 m depth, third used for receiving
- 2 signal generating oscilloscopes synchronized
- Underwater speed of sound measured to be $1430.3 \frac{\text{m}}{\text{s}}$ using CTD Sensor
- Test runs done with code degrees of 10, 9, and 8, repeated with decreased signal intensity for lower SNRs

anchor	distance to R	distance to R'
A	4.1 m	9.66 m
B	10.74 m	16.3 m



Real world setup - results



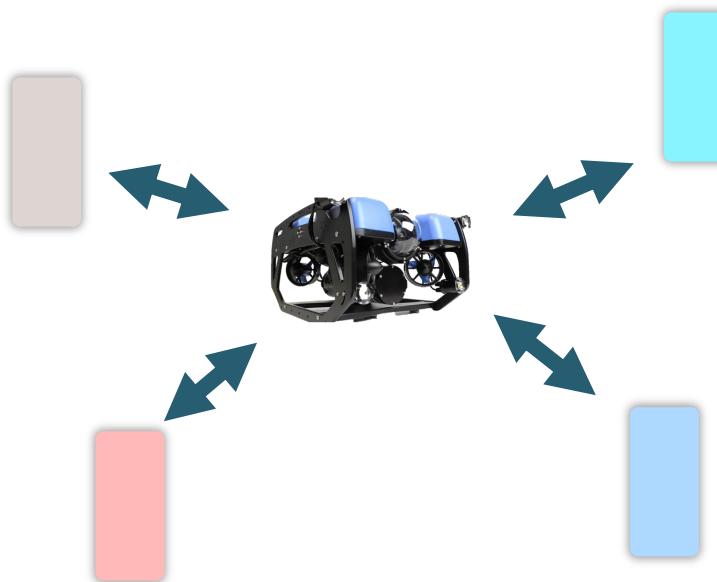
- signals of 51ms vs 2.5ms length (10th vs 9th deg. code)
- Values vary by 10cm
- Decreased SNR shifts the position overall
- Highest code degree most suitable

Project work results

- Optimal orthogonal pseudorandom code **gold codes** selected for satisfactory properties
- 3D position localization algorithm developed & effectively simulated with 4 anchors
- Code of 10th deg. yields usable results even with low SNR

Objectives of improvement

- CA-CFAR algorithm effective for peak detection but needs improvement
- Room for improvement by alternative CFAR algorithm (os-CFAR) & exploration of other peak detection methods
- Future research of evaluating 3d position performance in real-world scenarios.

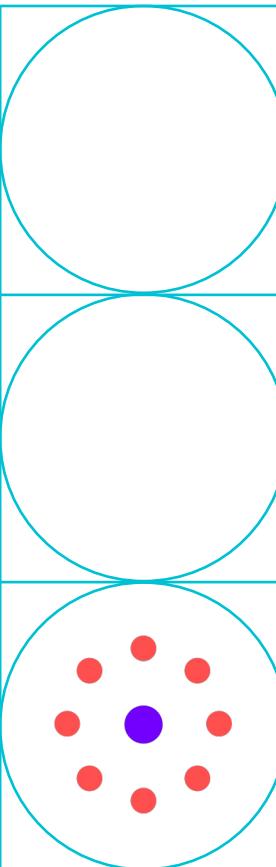


Literature and sources

- *Hermann Rohling. Ordered statistic cfar technique - an overview. In 2011 12th International Radar Symposium (IRS), page 635, 2011*
- *Ralph Bucher and Durga Misra. A synthesizable vhdl model of the exact solution for three-dimensional hyperbolic positioning system. VLSI Design, 15, 2002*
- *P. van Walree, R. Otnes, and T. Jenserud, Watermark: A realistic benchmark for underwater acoustic modems, in 2016 IEEE Third Underwater Communications and Networking Conference (UComms), Aug 2016*

Thanks for your
patience! Questions?

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