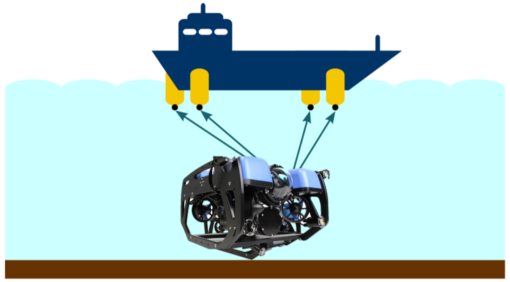
Orthogonal Codes for Acoustic Underwater Localization



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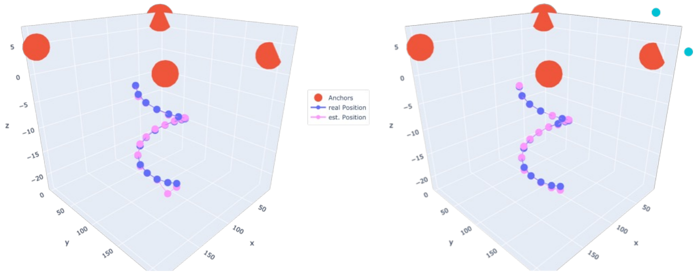
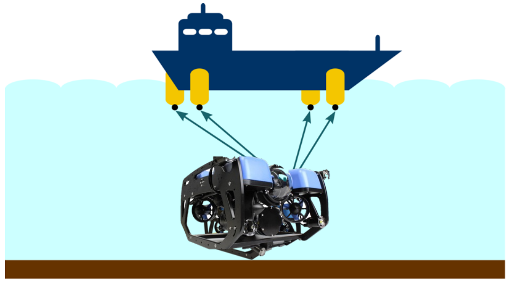


Sergej Keller

Content



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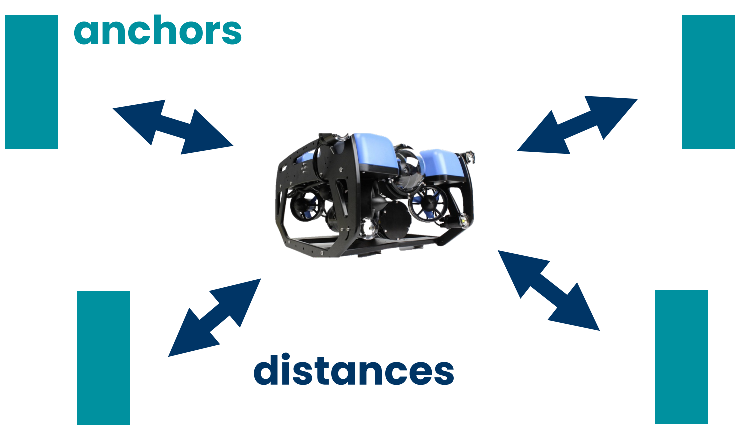
Motivation

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



Concept

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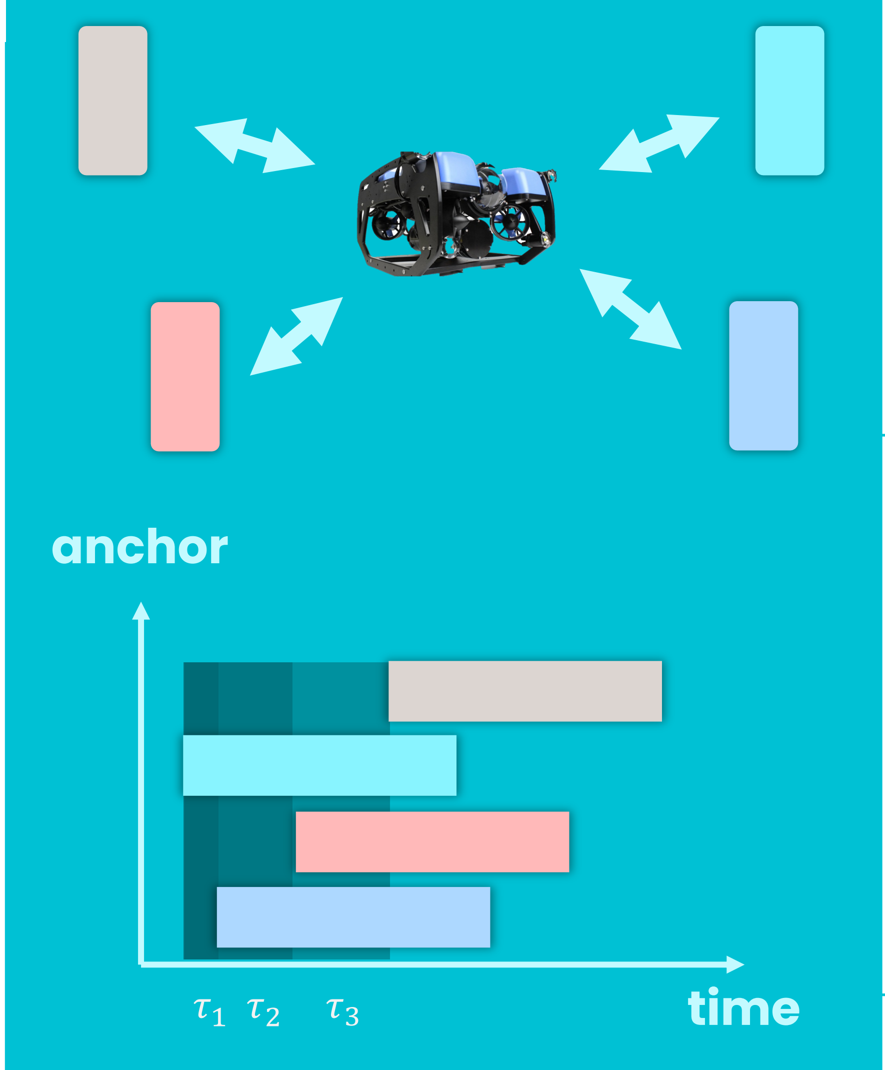
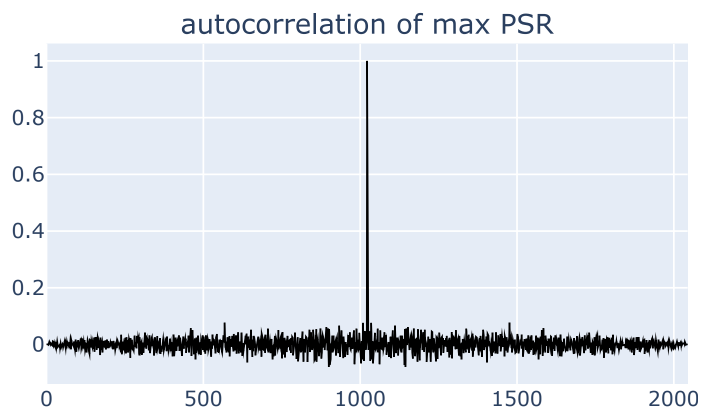
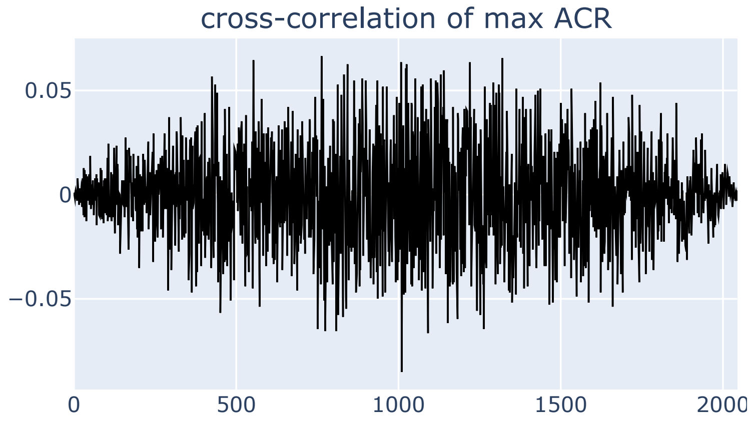
- Acoustic signals from anchors
  - Send synchronized by hydrophones
  - Challenges like multipath propagation & noise
- Time Difference of Arrival (TDOA)
  - Correlation technique to estimate position
  - Works great with orthogonal codes
- Orthogonal PN codes
  - Separable signals
  - Already in use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



Orthogonal PN codes – overview





m-sequences | Kasami codes | Gold codes

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

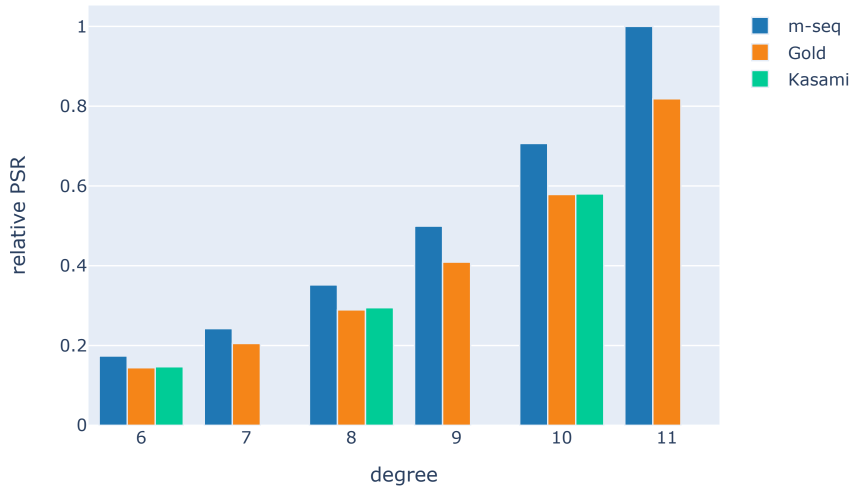
Evaluation parameters

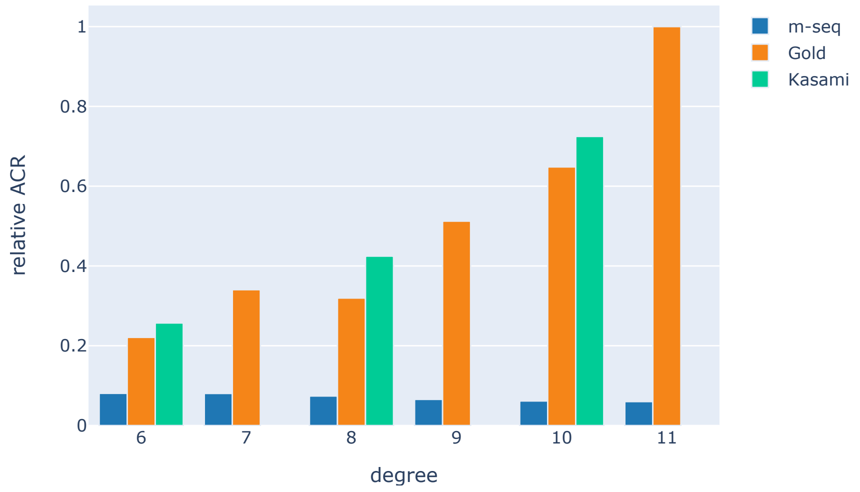
- **P**eak to **S**idelobe **R**atio (PSR)
  → increases with peak clarity
- **A**utocorrelation to **C**ross-correlation **R**atio (ACR)
  → increases with code separability, orthogonality

Evaluation results

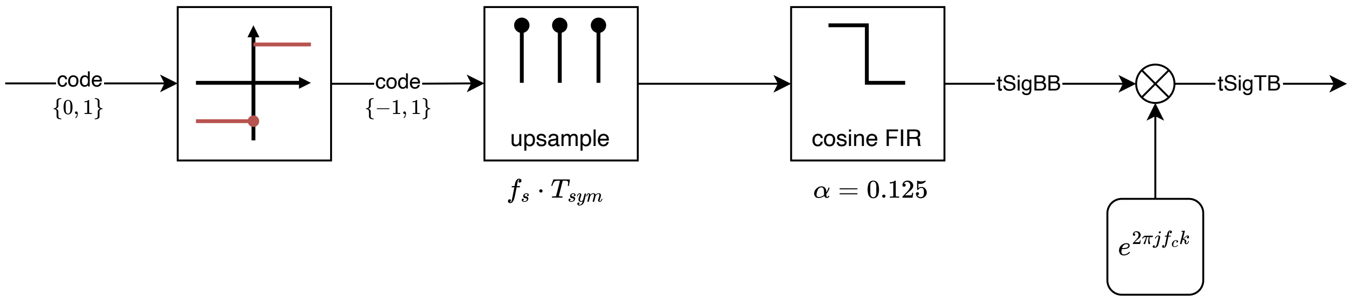
- M-sequences have worst separability
- Gold codes and Kasami codes are on the same level
- Gold codes chosen because of larger sets
  → scalability of anchors

Gold codes



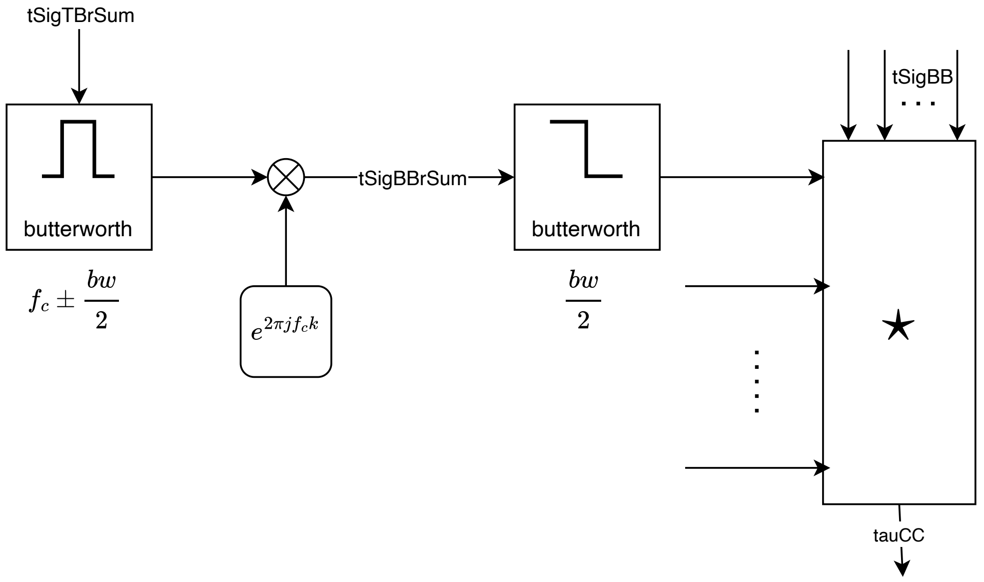


Signal processing – sending & receiving



Sending signal

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



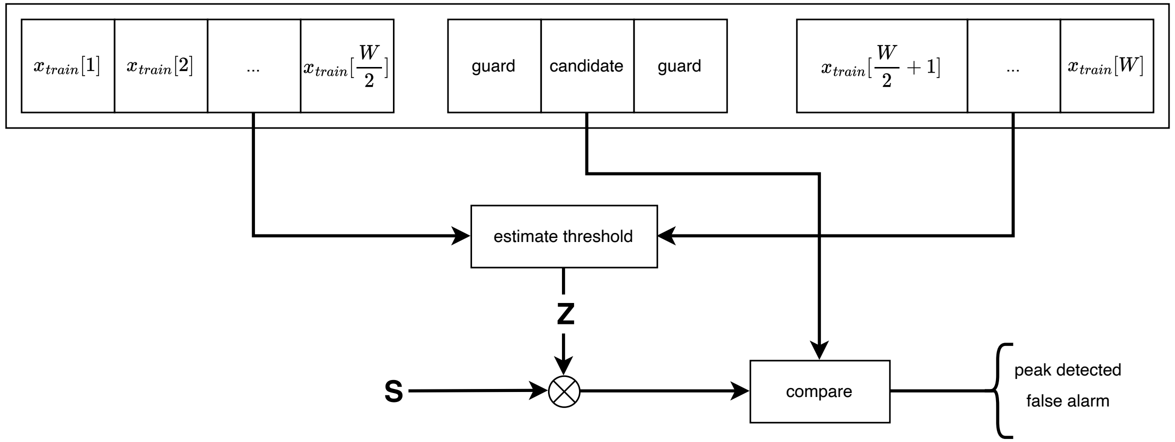
receiving signal

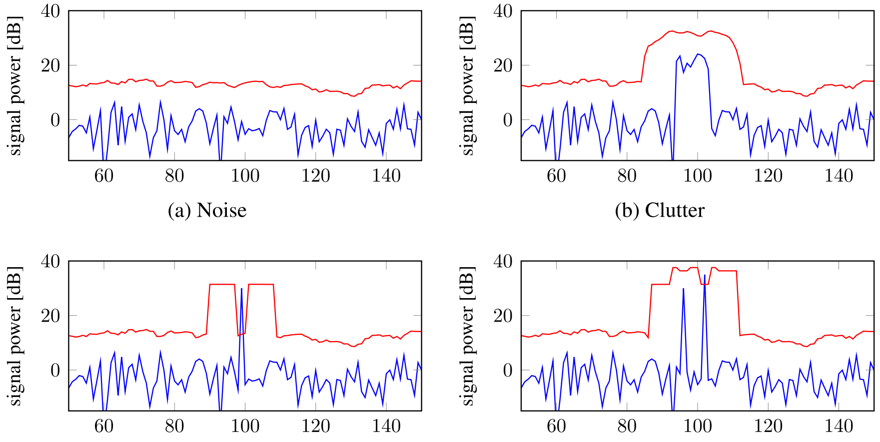
- Sum of signals filtered & back shifted to baseband
- Second filter removing shifting characteristics
- Cross correlation with original signals

Peak detection – CA-CFAR

Localization procedure

- **C**ell **A**veraging – **C**onstant **F**alse **A**larm **R**ate
- 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





(a) Noise (b) Clutter

(c) Single Target (d) Two Targets

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

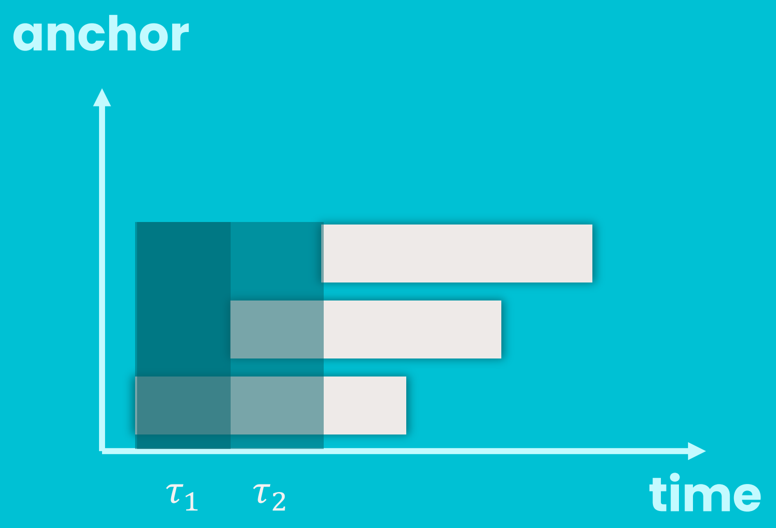
Alternative cell measure

- **O**rdered **S**tatistics – **C**onstant **F**alse **A**larm **R**ate
- Using median instead of averaging
- Not used in project

Localization

Localization algorithm

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

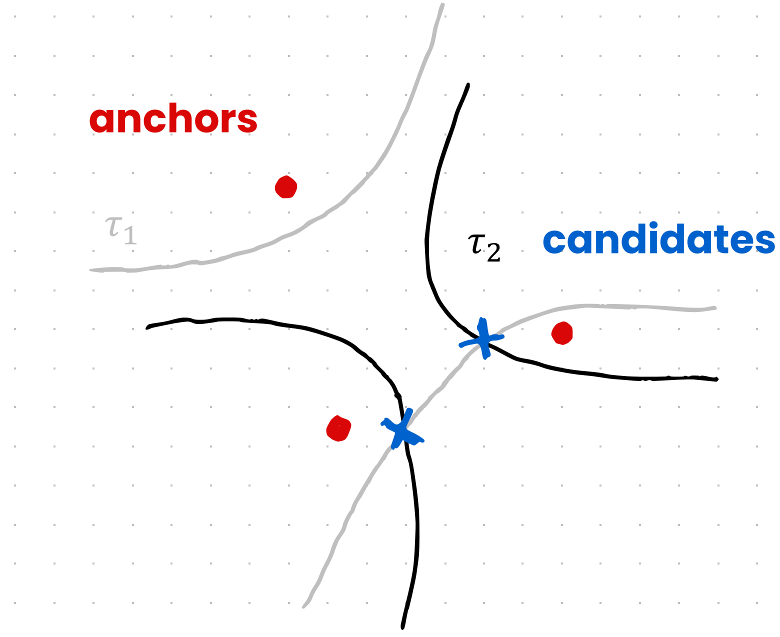


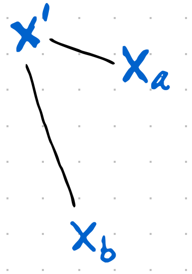
[Ralph Bucher and Durga Misra. A synthesizable vhdl model of the exact solution for three-dimensional hyperbolic positioning system. VLSI Design, 15, 2002]

Localization

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





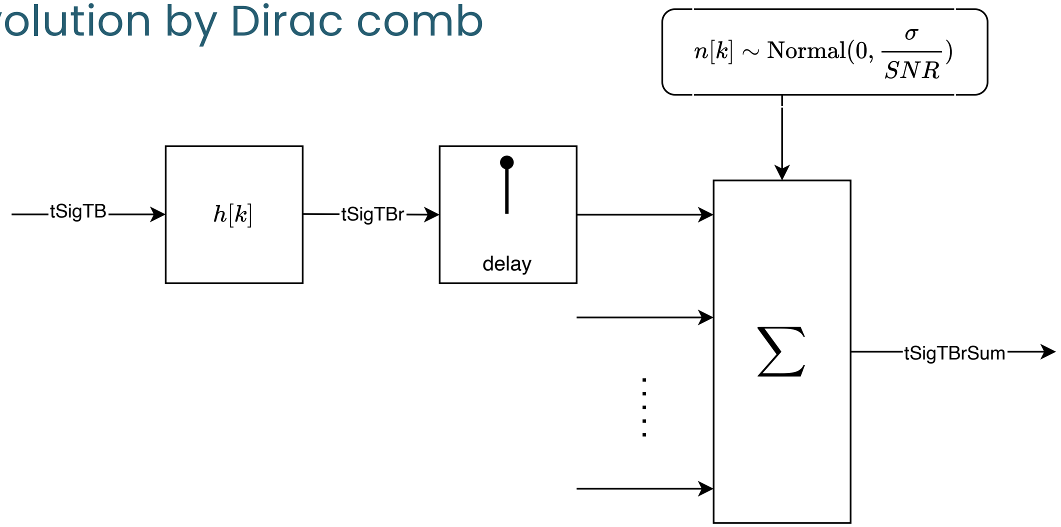
$$z = \begin{cases} z_a & \text{if} \quad |z_a - z'| < |z_b - z'| \\ z_b & \text{else} \end{cases}$$

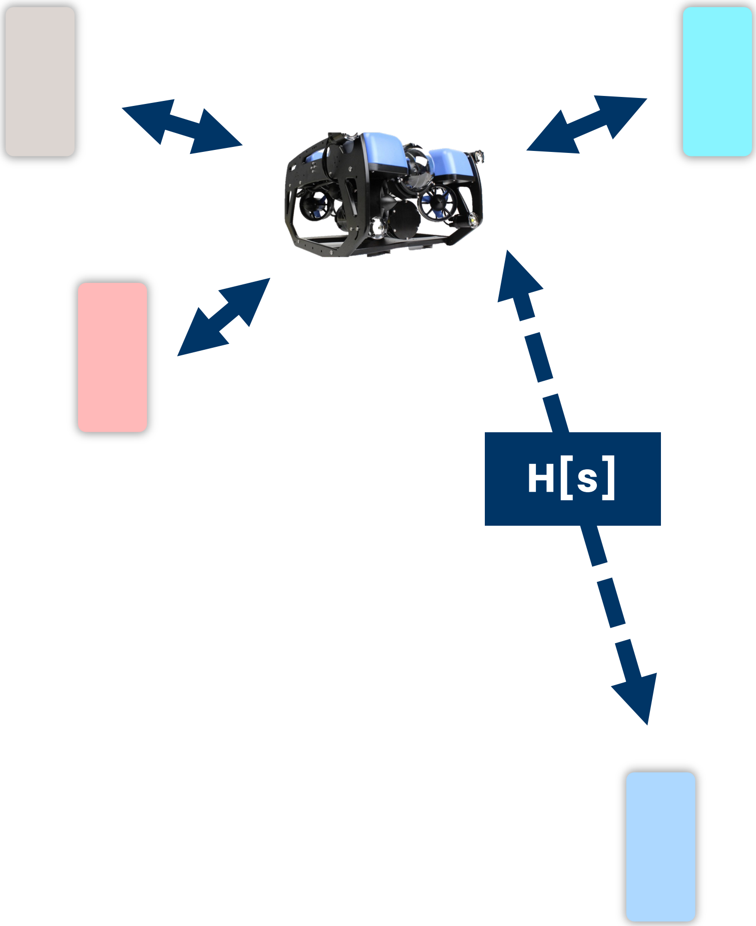
[Ralph Bucher and Durga Misra. A synthesizable vhdl model of the exact solution for three-dimensional hyperbolic positioning system. VLSI Design, 15, 2002]

Simulation

Simulation process

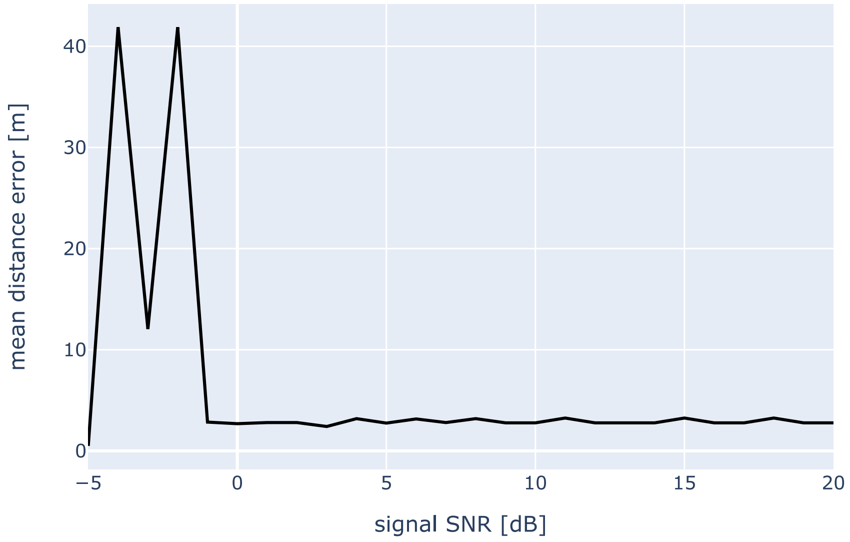
- Delays, calculated from example coordinates, add to signals
- Delayed signals get summed up
- To the sum a by SNR adjustable noise gets added
- Additional **Watermark simulation**
  - Uses different channels
  - Convolution by Dirac comb

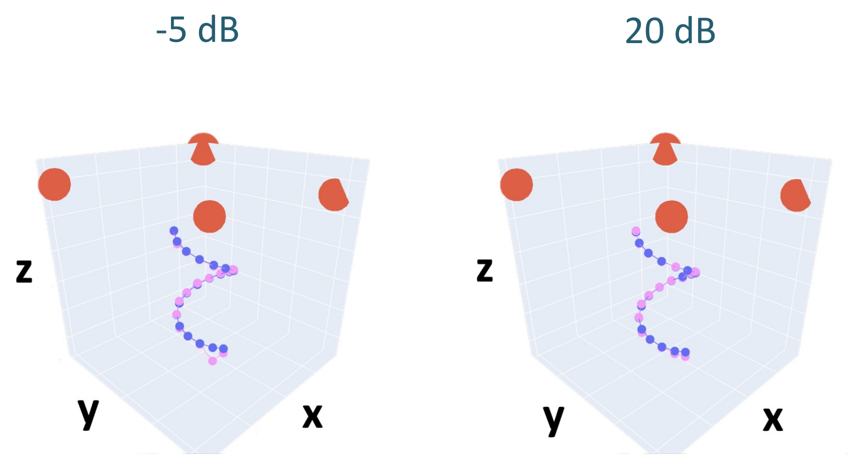


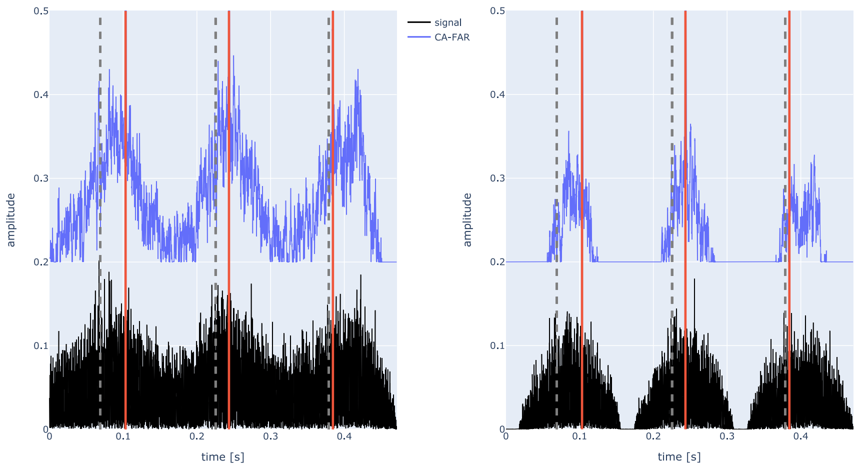


Simulation – results

- For simulation, a circular path & corresponding TDOA are generated
- 4 anchors placed above spanning a rectangular shape
- Different **levels of noise** and Watermark channels PLANE1 and CASTLE2 used
- Increasing noise highly rise the risk of false detection of peaks and therefore unreliable position data







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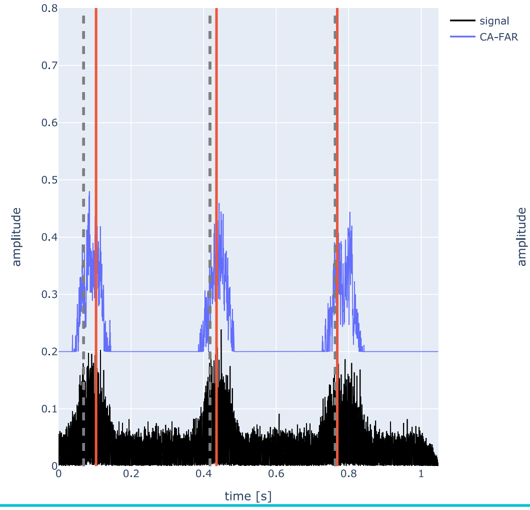
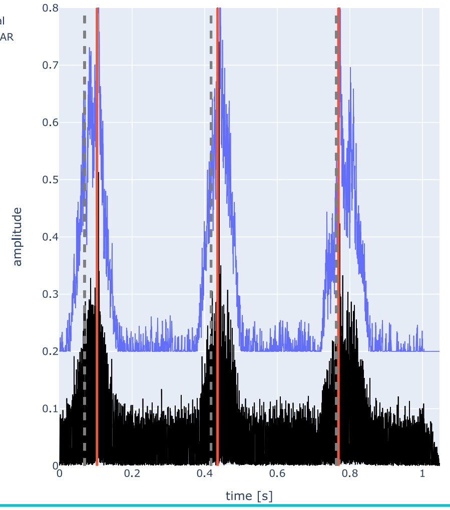
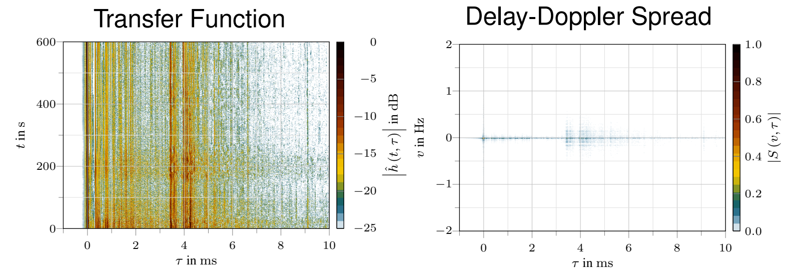
CASTLE2, -5dB



PLANE1, -5dB

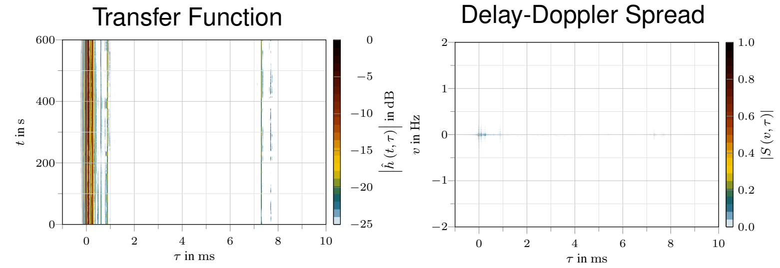


CASTLE2 Transmission Channel



[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]

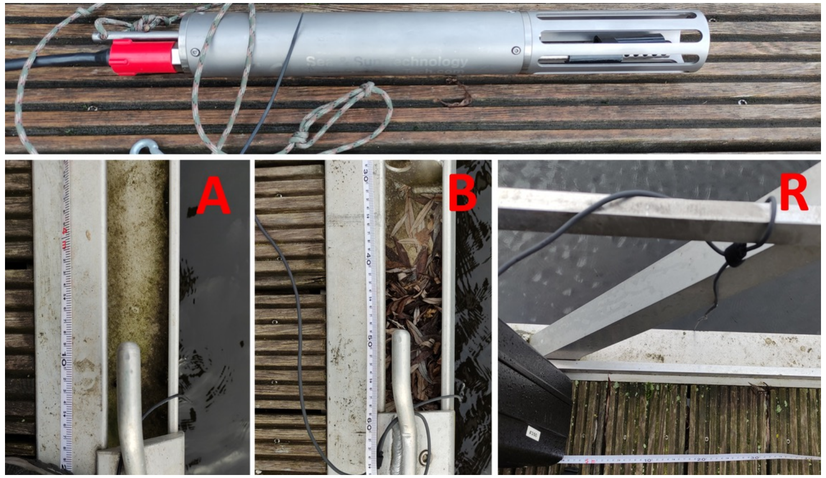
PLANE1 Transmission Channel



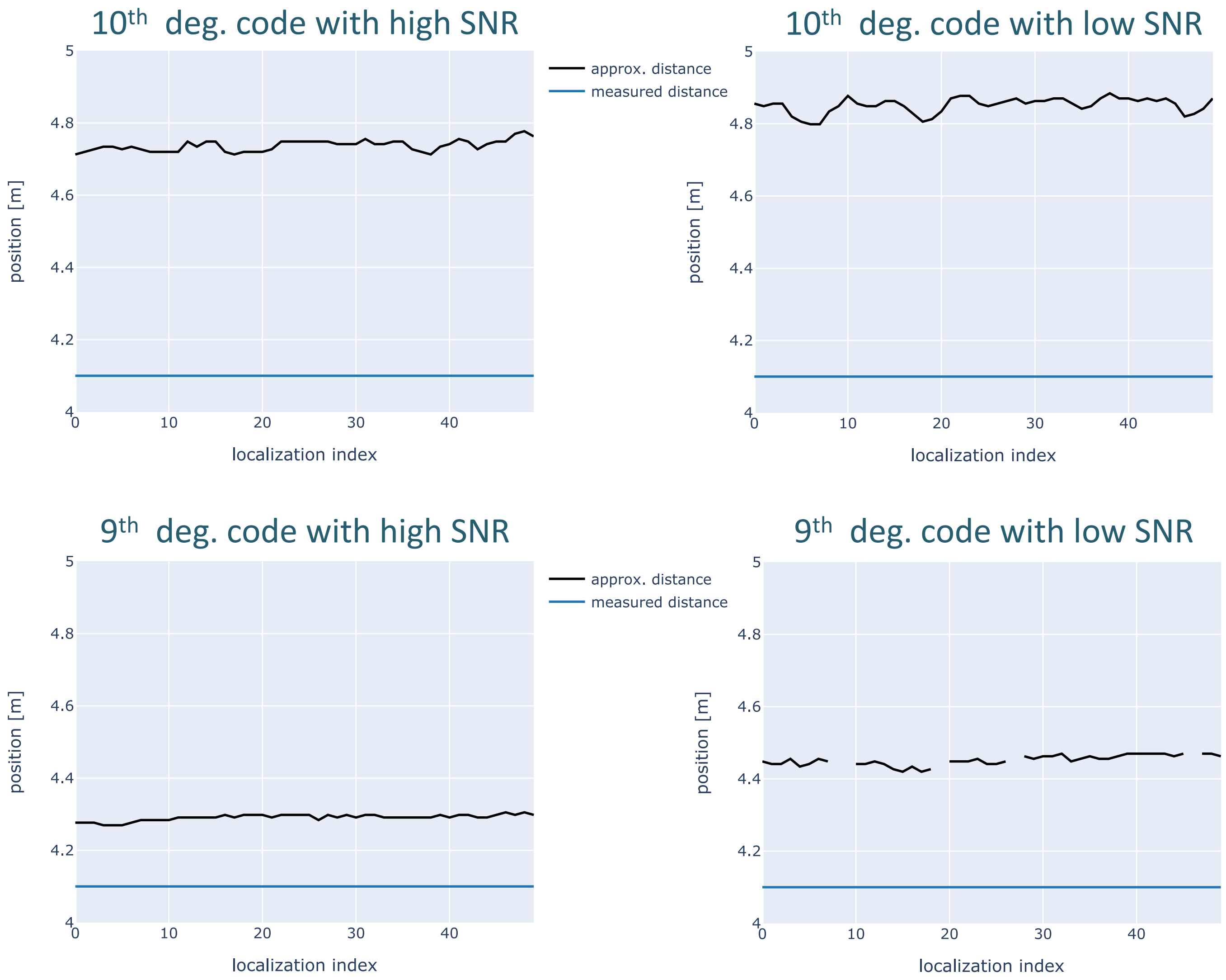
Real world setup

- 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 $\frac{\mathrm{m}}{\mathrm{s}}$ 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 (10^{th} vs 9^{th} deg. code)
- Values vary by 10cm
- Decreased SNR shifts the position overall
- Highest code degree most suitable

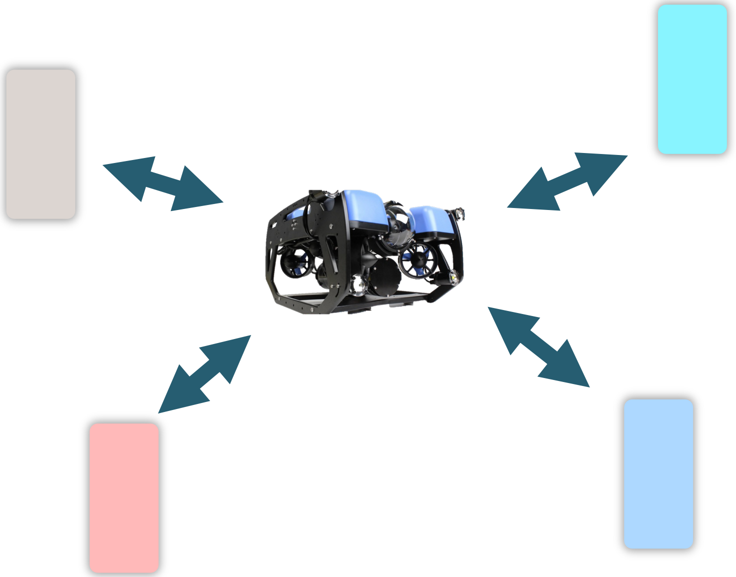
Conclusion

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 10^{th} deg. yields usable results even with low SNR
- Implementation in python

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

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Thanks for your patience! Questions?

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