Characterization and localization of oil leakages using passive acoustic techniques

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Introduction

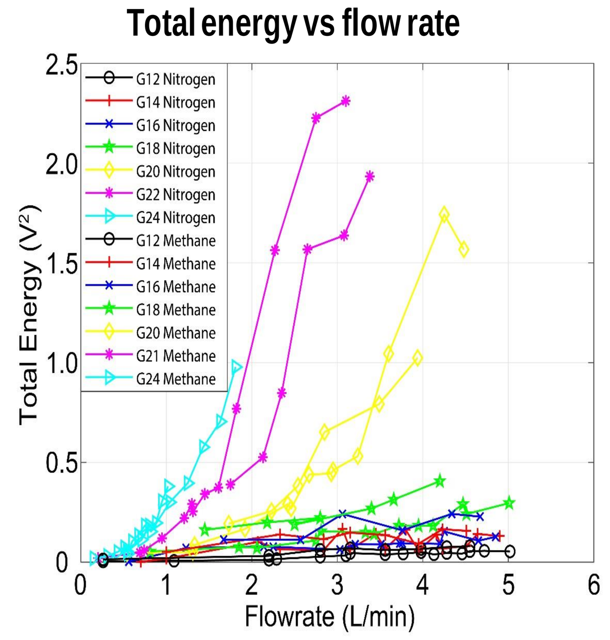
Rapid growth of oil production in the Gulf of Mexico increases the risk of oil spills. A monitoring system is essential to improve safety and reduce the risk of environmental damage. The leaked oil creates underwater sounds and can be recorded by acoustic sensors (hydrophones). This project is focus on developing a hydrophone network-based real-time passive monitoring system for detecting, locating, and characterizing hydrocarbon leakages undersea.

The tasks of the research are:

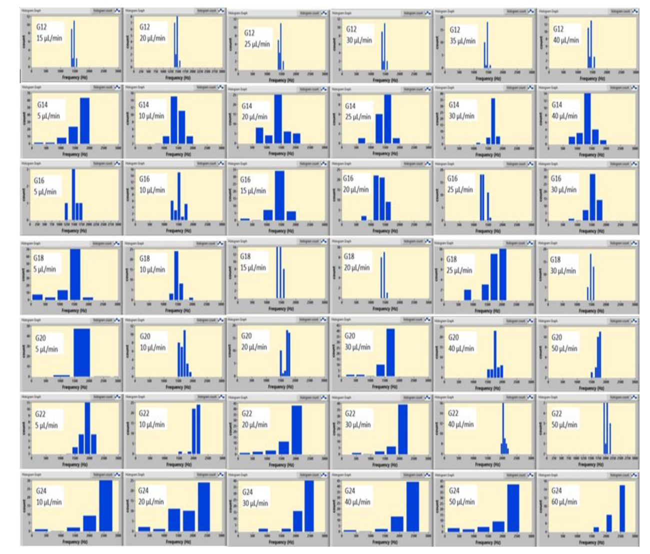
1. Conduct a laboratory study to simulate hydrocarbon leakage under controlled conditions (pressures, flow rates, opening sizes, and types of leakages), to record the oil leakage-induced underwater sound, and to establish the correlation between frequency spectra and oil leakage properties, such as oil-jet intensities and speeds, bubble radii and distributions, and crack sizes.
2. Implement and develop acoustic bubble modeling for estimating features and strength of the oil leakage
3. Develop a set of signal processing and triangulation algorithms for leakage identification and localization.

Picture of constant flow bubbles

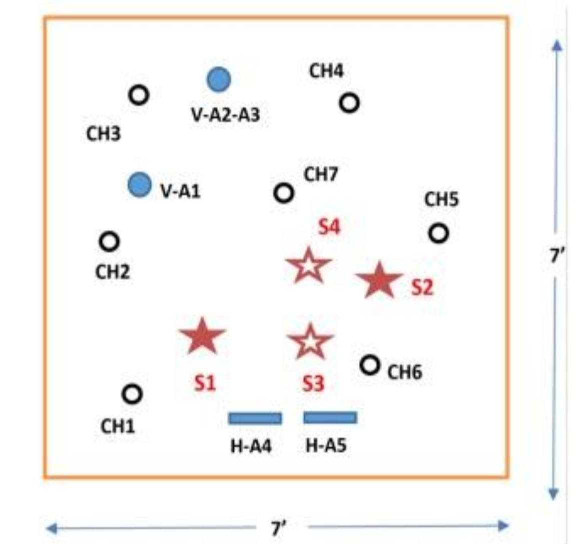
Total energy vs flow rate



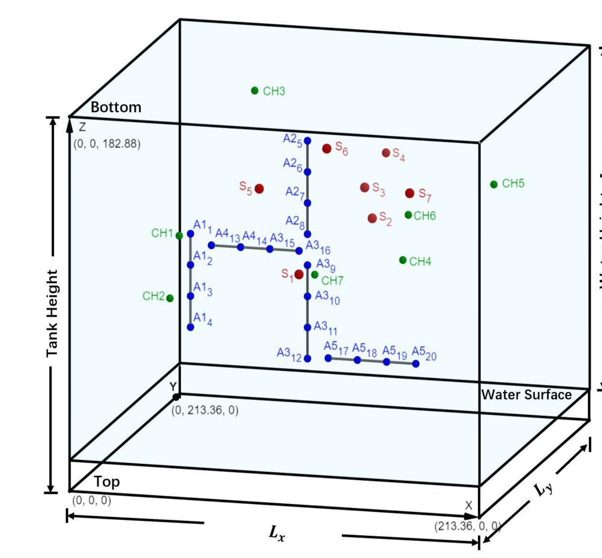
The histograms of the resonant frequency



Top view of hydrophones, hydrophone arrays, and sources



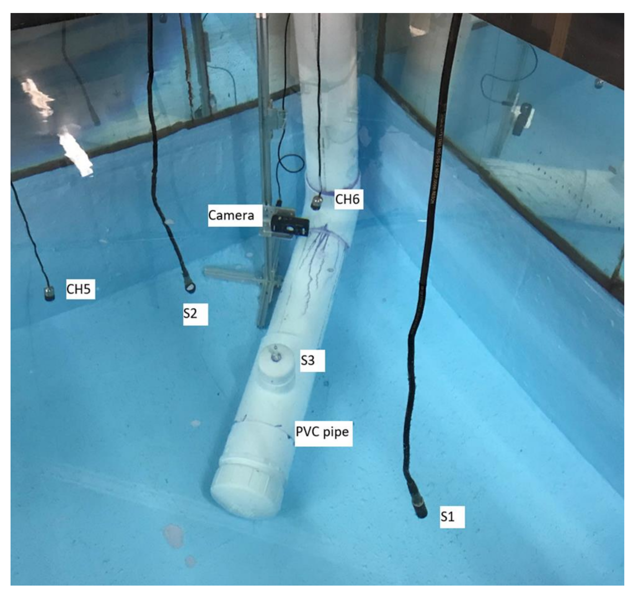
3D view of hydrophones, hydrophone arrays, and sources



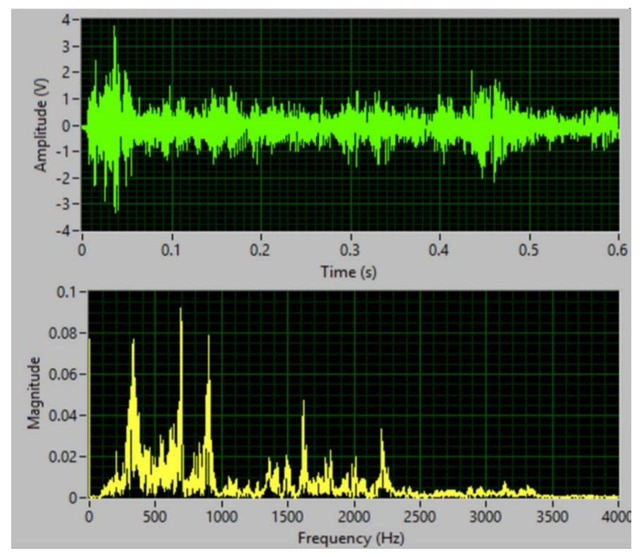
Localization results using three water tank models with grids (10x10x10)

Bubble Sources		Model	X [m]	Y [m]	Z [m]	RMSE [m]
S4	True Location		1.460	1.120	1.480	
	Estimated Location	M1	1.600	0.960	1.427	0.127
		M2	1.387	0.960	1.427	0.106
		Proposed	1.387	0.960	1.595	0.121
S5	True Location		0.710	1.030	1.290	
	Estimated Location	M1	0.533	1.173	1.595	0.220
		M2	0.533	1.173	1.595	0.220
		Proposed	0.533	1.173	1.595	0.220
S6	True Location		1.020	1.185	1.470	
	Estimated Location	M1	0.960	0.960	0.084	0.811
		M2	0.960	1.173	0.420	0.607
		Proposed	0.960	1.173	1.091	0.222
S7	True Location		1.465	1.135	1.290	
	Estimated Location	M1	1.600	0.960	1.427	0.150
		M2	1.387	0.960	1.091	0.159
		Proposed	1.600	1.173	1.091	0.141

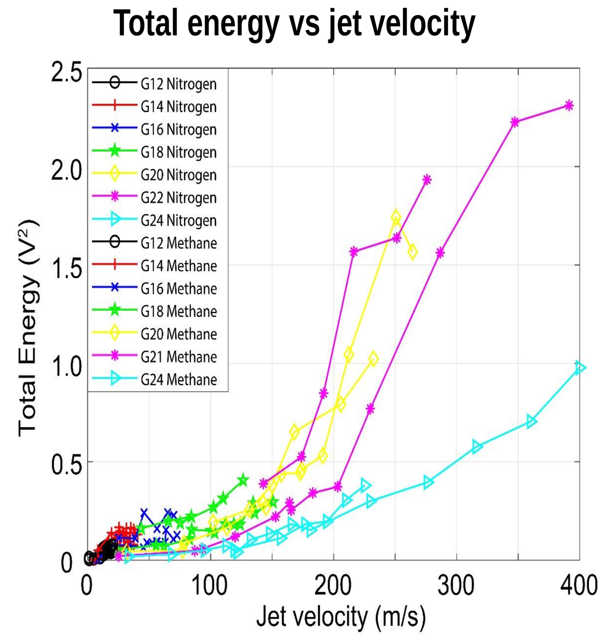
Water tank experimental setup



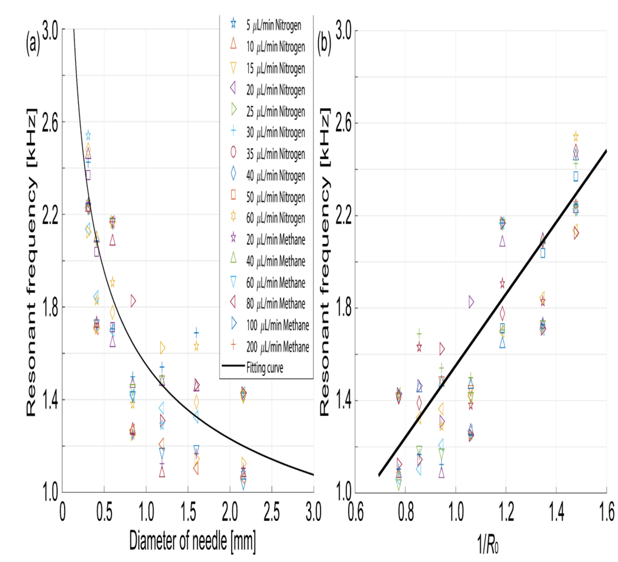
Signals from constant flow bubbles



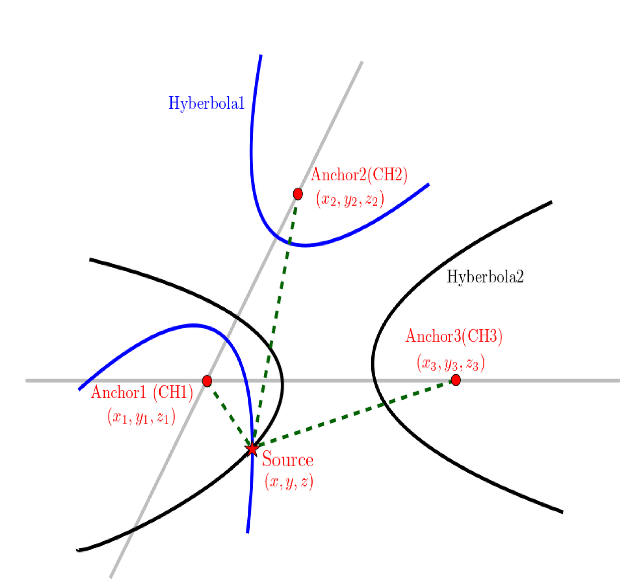
Total energy vs jet velocity



The resonant frequency vs the diameter of the needles and the radius of a spherical bubble



TDOA-based localization concept



The spectra ratio-based localization

Algorithm Framework of spectra ratio-based localization

Input:

1: The water tank and grids dimension, receivers' location and number

2: The recorded signal by receivers, $p_i, i = 1, \ldots, 7$

Output:

3: Calculate three different model's* Green's functions dictionary with help of step1, $G(\vec{r}_i, \vec{r}_s, \omega)$

4: Transfer p_i to frequency domain $P_i(\omega)$ with interested frequency range 600Hz to 2KHz.

5: Calculate spectra ratio $S_{m,n}(\vec{r}_s, \omega)$ with help of $G(\vec{r}_i, \vec{r}_s, \omega)$ and $P_i(\omega)$

6: Calculate the rms of $S_{m,n}(\vec{r}_s, \omega)$ in dB scale

7: Calculate detection factor of all receivers with help of step 6

8: Estimation result is $\vec{r}_s$ which maximize detection factor

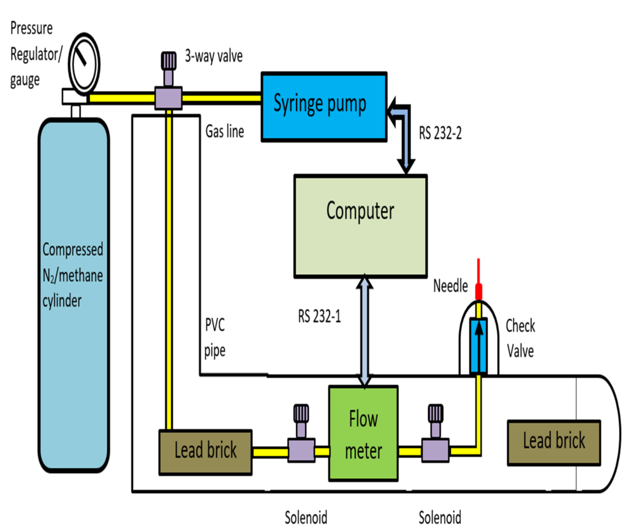
9: Return $\vec{r}_s$

* M1 means traditional 'Dirichlet Model', M2 means 'Including Leakage Through the Walls Model', "Proposed" means 'Proposed New Water Tank model'.

Localization results with two grid dimensions

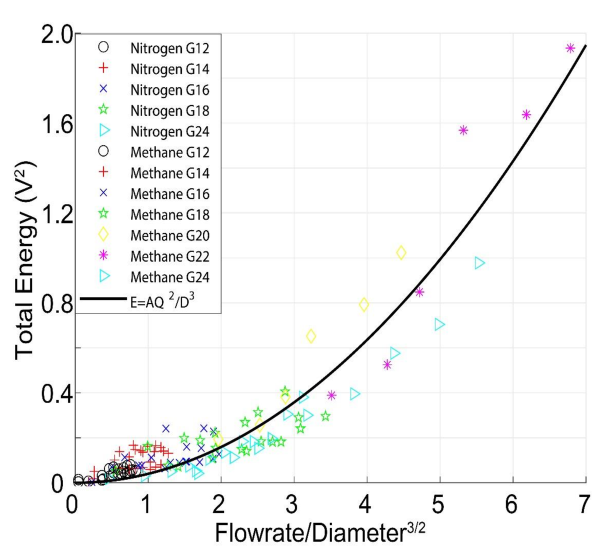
Bubble Source S6	Grids Dimension	Model	X [m]	Y [m]	Z [m]	RMSE [m]
True Location			1.020	1.190	1.470	
Estimated Location	10 X 10 X 10	M1	1.170	0.960	1.090	0.270
		M2	0.960	1.170	0.420	0.610
		Proposed	0.960	1.170	0.420	0.610
	20 X 20 X 20	M1	1.120	1.010	0.460	0.590
		M2	1.120	1.010	0.970	0.310
		Proposed	1.120	1.010	1.130	0.230

Bubble generation system

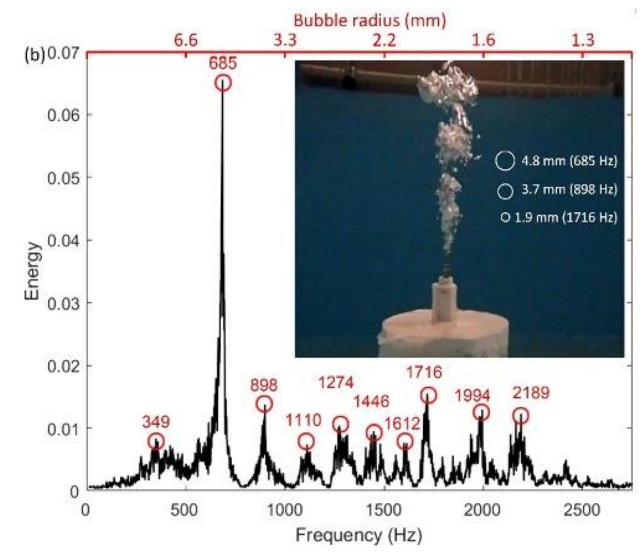


Picture of a few bubbles

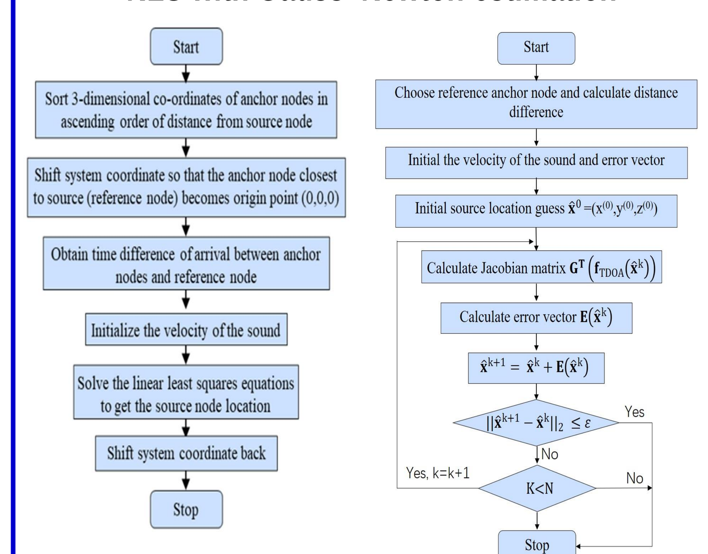
Total energy as a function of flow rate and effective bubble diameter



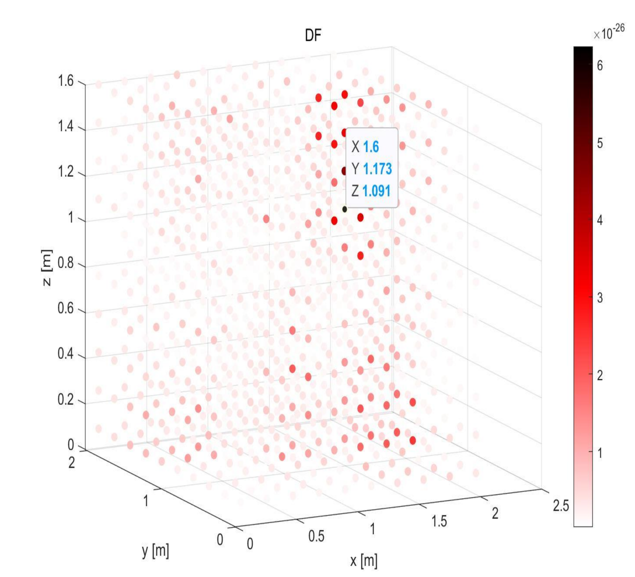
Frequency spectrum, peak frequencies, and the corresponding bubble radii



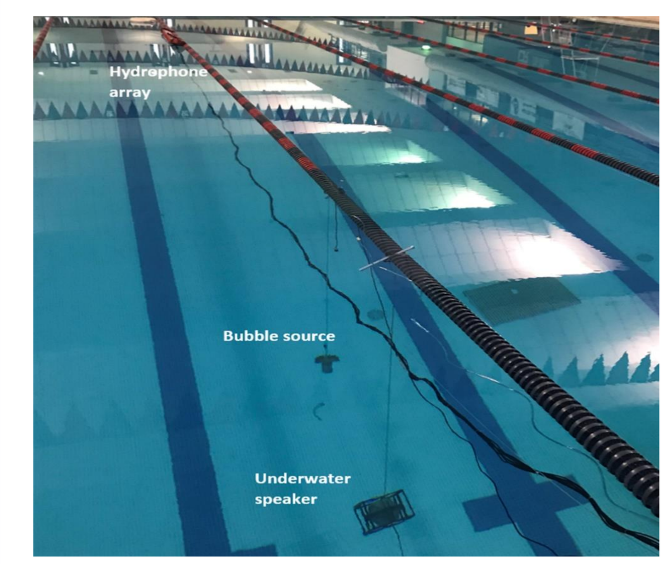
The flowcharts for Linear Least Square and NLS with Gauss–Newton estimation



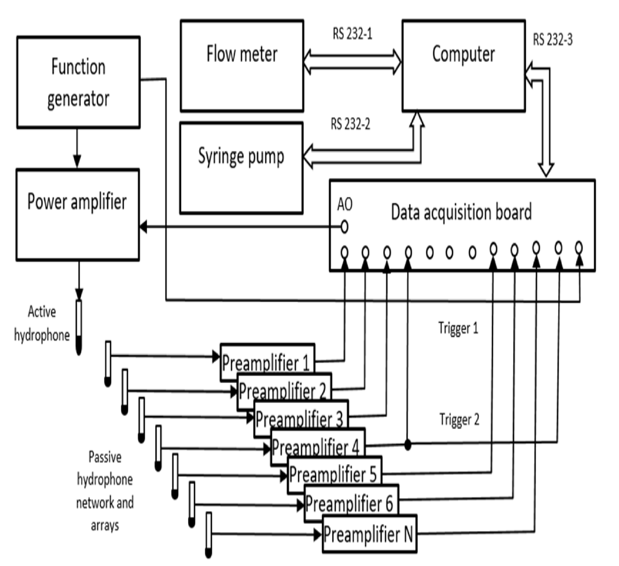
The detection factor (DF) in 3D space



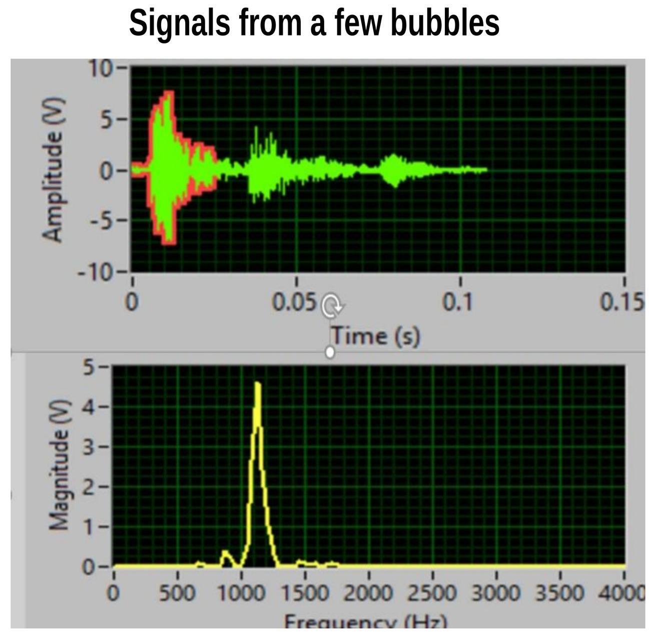
Swimming pool test



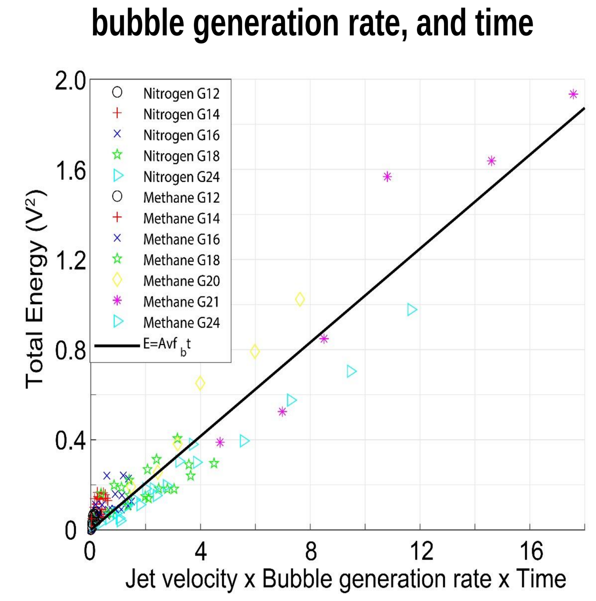
Instrument control and data acquisition



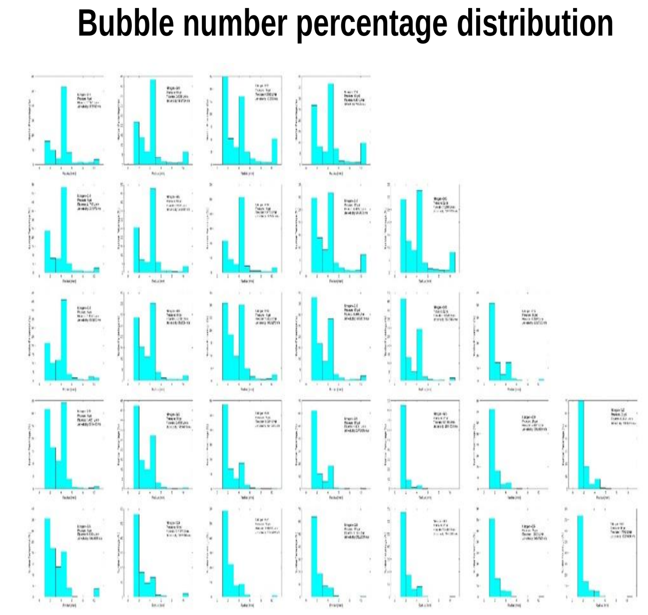
Signals from a few bubbles



Total energy as a function of jet velocity, bubble generation rate, and time



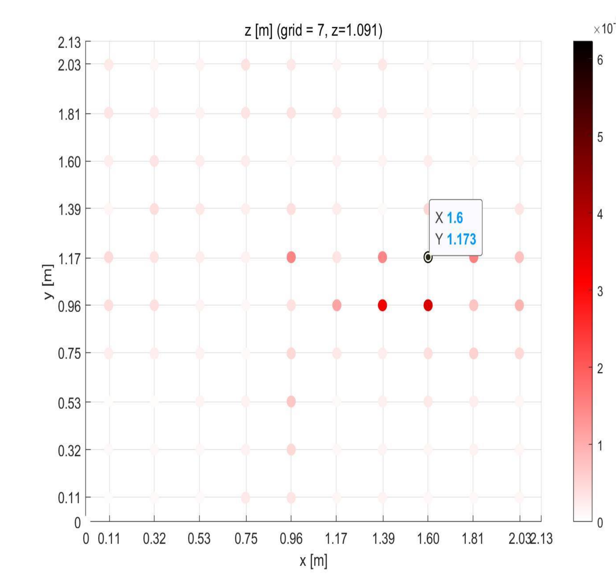
Bubble number percentage distribution



Localization results using LLSE and NLS with Gauss–Newton estimation methods

Sources	Signal Type	True Location (cm)	Estimated Location (cm)		RMSE (cm)	
			LLSE	NLS	LLSE	NLS
S1	Electric	(174.0, 73.0, 136.0)	(180.6, 75.8, 134.8)	(179.6, 76.7, 135.6)	4.20	3.88
S2	Electric	(90.0, 64.0, 115.0)	(90.6, 65.1, 105.5)	(90.3, 65.3, 107.0)	5.53	4.68
S3	Bubble	(139.5, 52.5, 145.0)	(138.4, 52.4, 151.1)	(136.9, 53.1, 144.0)	3.58	1.65
S4	Bubble	(136.0, 112.5, 140)	(133.4, 115.5, 146.2)	(136.3, 115.6, 145.6)	4.25	3.70

The DF in 2D (x-y plane) space



Conclusions

- Acoustic signatures in terms of total energy, resonate frequency, and frequency spectrum can be used to estimate the intensity, crack size, and bubble size distribution of oil leakages
- Localization algorithms were able to determine the locations of bubble sources

Acknowledgment

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