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Final Report Acoustic Color Quality Assessment

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J. Daniel Park

Applied Research Laboratory The Pennsylvania State University

Phone: (814) 865-7507, fax: (814) 863-7841

Email: jdp971@arl.psu.edu

Accomplishments

What were the major goals and objectives of the project?

There is growing interest in using acoustic color, which is the aspect-dependent target strength response of an object, as a data representation suitable for feature extraction to improve ATR (automatic target recognition) performance for mine countermeasures (MCM). Compared to SAS (synthetic aperture sonar) imagery, acoustic color is believed to be less sensitive to certain uncompensated errors for the purpose of detecting and classifying underwater mines. But, to the best of the authors' knowledge, in-depth characterization to verify this belief has not been performed. Since some type of coherent beamforming is often used to create acoustic color measurements in the ocean environment, the data products have the potential to be corrupted by phase error. In addition, the creation of acoustic color from stripmap collections means that the signal-to-noise ratio (SNR) may vary as a function of frequency and aspect. The goal of this project is to establish the means by which degradations in acoustic color performance can be characterized and understood. Where possible, this understanding will be expressed in the context of an ATR feature space.

What was accomplished towards achieving these goals?

During the period of performance (March 15, 2015 – March 31, 2019), we have investigated various signal processing methods for acoustic color and methods for quantifying the quality of acoustic color. The work accomplished during this effort can be summarized as follows: 1) Investigated the representation space for Acoustic Color and other related spatial spectrum domains to demonstrate the utility of transforming between these domains for the purpose of assessing information quality, 2) Development of two different definitions of Acoustic Color

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14. ABSTRACT There is growing interest in using acoustic color, which is the aspect-dependent target strength response of an object, as a data representation suitable for feature extraction to improve ATR (automatic target recognition) performance for mine countermeasures (MCM). Compared to SAS (synthetic aperture sonar) imagery, acoustic color is believed to be less sensitive to certain uncompensated errors for the purpose of detecting and classifying underwater mines. The goal of this project is to establish the means by which degradations in acoustic color performance can be characterized and understood. Where possible, this understanding will be expressed in the context of an ATR feature space. We have investigated various signal processing methods for acoustic color and methods for quantifying the quality of acoustic color. The work accomplished during this effort can be summarized as follows: 1) Investigated the representation space for acoustic color and other related spatial spectrum domains to demonstrate the utility of transforming between these domains for the purpose of assessing information quality, 2) Development of two different definitions of acoustic color quality primarily utilizing the phase of acoustic color, 3) Investigation of representation domain trade-offs with respect to the acoustic color quality, 4) Demonstration of the utility of developed quality measures.					
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quality, 3) Investigation of representation domain trade-offs with respect to the Acoustic Color quality, 4) Demonstration of the utility of developed quality measures.

Spatial Spectrum Domain Representation

We have applied the transformation from acoustic color (frequency vs. aspect angle) to the spatial spectrum domain (k_x, k_y) and stripmap measurement domain (k_u, k) to various objects of interest included in PONDEX 09/10 data, as seen on the right in Figure 1. Many object's signatures have straight and simple shapes in this representation, and this characteristic makes this representation well-suited for quality assessment since the information density is not frequency-dependent as is the case with the standard acoustic color representation in (θ, f) . However, while the straight vertical and horizontal highlights are easy to recognize for their high SNR in this spectral representation, other physical signatures are less obvious and difficult to identify, such as the elastic response of the object.

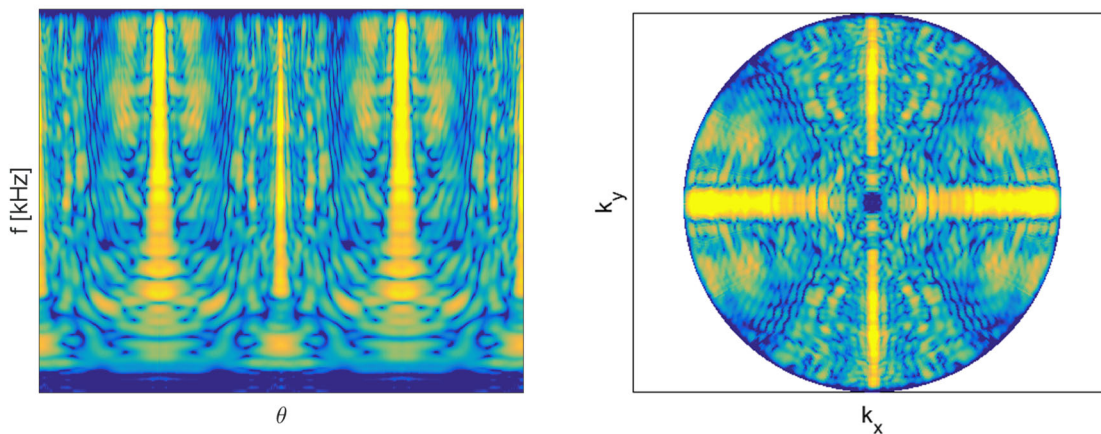


Figure 1 A comparison of Acoustic Color representation and spatial spectrum. The highlight signatures transform into simpler geometric shapes in the spatial spectrum representation.

Acoustic Color Quality Metric – Phase Continuity

Figure 2 is a comparison of acoustic colors for a man-made object and sea floor. The top row is the magnitude of the complex acoustic color and the bottom row represents the measured phase. It is evident the plots on the left column show spectral structures from which features can be measured. On the other hand, plots on the right column exhibit little structure from which information can be extracted. One of the observations made from this comparison is that the phase of strong features exhibit smooth transitions while the phase of the sea floor show random fluctuations.

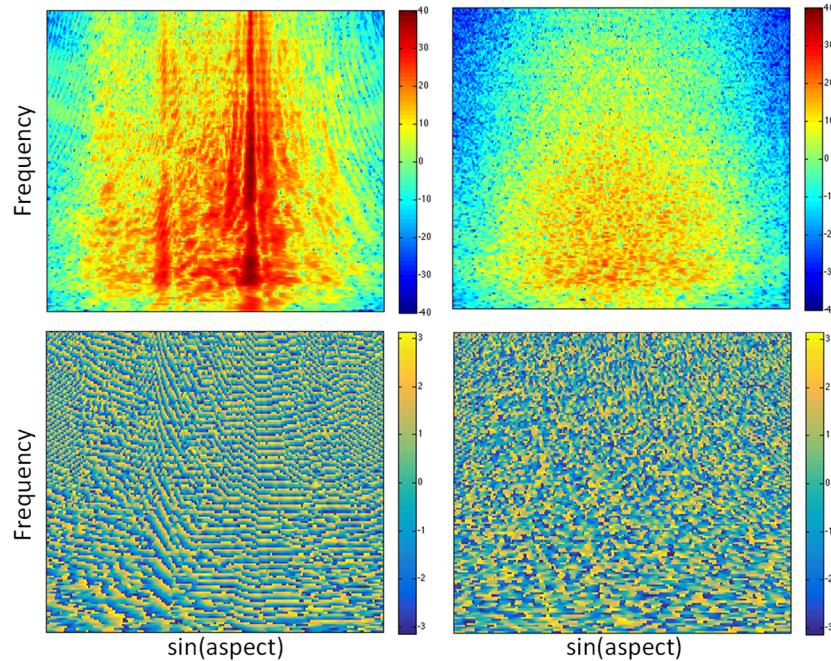


Figure 2 Magnitude and phase of complex Acoustic Colors, for a man-made object on the left and the sea floor on the right

Based on this observation, a quality metric for Acoustic Color called phase continuity is measured by unwrapping the phase of the complex acoustic color and measuring the local phase variance map, as illustrated in Figure 3. In this work, the 2-D phase unwrapping step was done by averaging the unwrapped phases in the horizontal and vertical direction. The local variance map in Figure 3 (f) seems to be consistent with the magnitude of the complex acoustic color, but it is easier to see the fine harmonic structure, especially in the right third of the plot. For target responses that inherently change slowly, both over frequency and aspect, this measure indicates the stability of the phase, not interfered by random fluctuations.

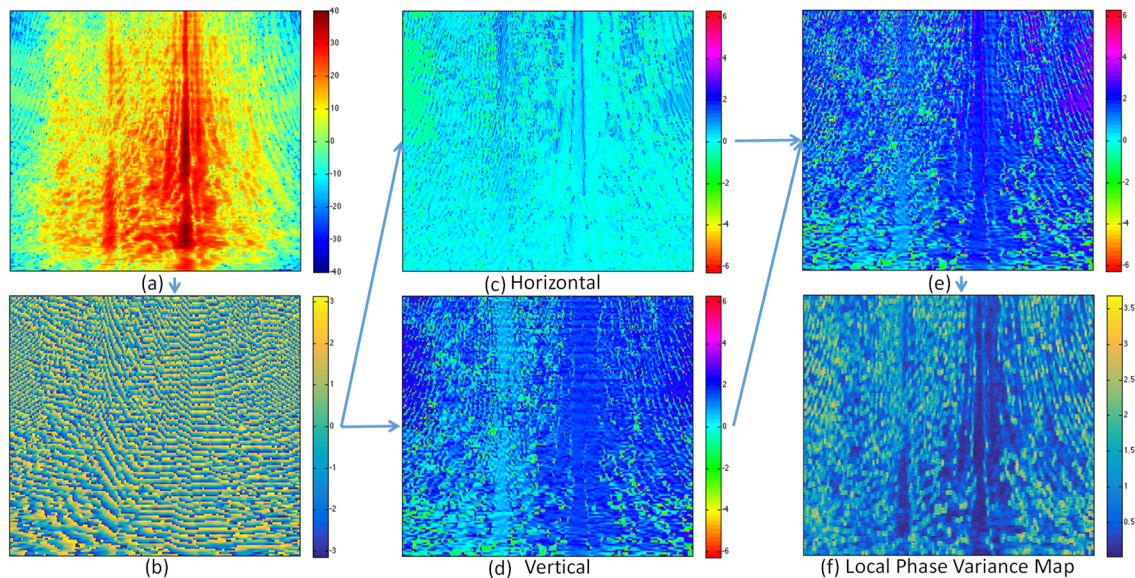


Figure 3 An illustration of generating the local phase variance map. The 2-D phase unwrapping is done by averaging the two 1-D phase unwrapping, and the final phase variance is generated by measuring the sample variance for each sub-block.

A cumulative histogram of this local phase variance map is a useful representation to measure the portion of the map with low variance, as shown in Figure 4. A steeply rising plot implies that a large portion of the phase is slowly varying. The value of the cumulative histogram at a given threshold variance indicated by the vertical dashed-line, referred to as the phase continuity score in this work, is a summary statistic that describes the portion of the local phase variance map with low phase variance measured from a complex acoustic color, which is computed from a cropped image previously discussed.

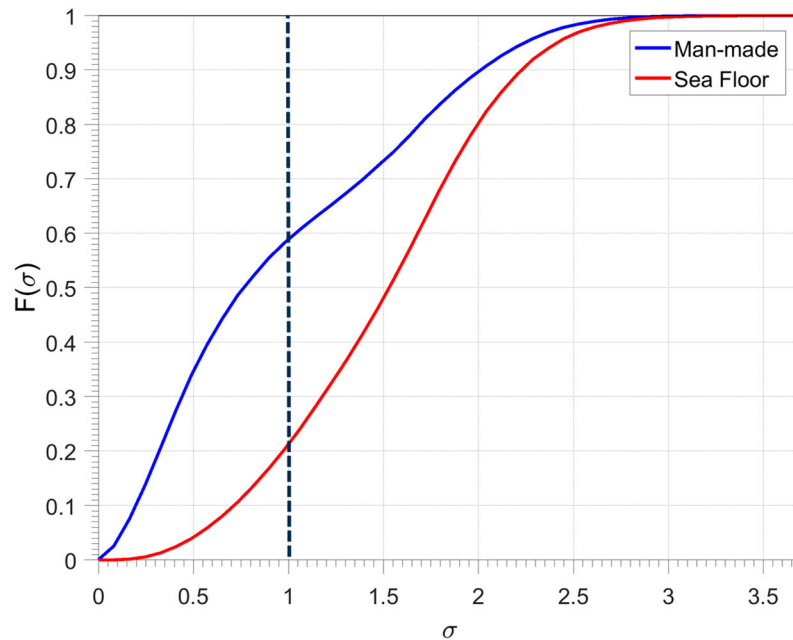


Figure 4 The cumulative histogram of the local phase map for man-made object and sea floor. Steeply rising curve implies large portion of the map is low variance indicative of smooth phase for the complex Acoustic Color.

Acoustic Color Quality Metric – Null Depth

Spectral representations, either (angle vs. frequency) or (k_x, k_y) , are expected to provide the ability to visualize object information that is not easily accessible in imagery, such as the elastic response or multiple scattering. Figure 5 is a comparison of Acoustic Colors for a solid aluminum cylinder and a hollow aluminum cylinder. While they are noticeably different, most of the differences are due to the geometric response and the elastic response from the hollow object that is not intuitively ‘visible’ from this representation. However, a time-varying acoustic color (TVAC), which is a series of time-gated Acoustic Color plots on a sliding window, demonstrates the ability to characterize these transient elastic responses and multiple scattering effects (Video provided in prior report).

One of the observations made on the TVAC is that the glint signature off the long edge, the narrow broadband signature in Figure 5, of both the solid cylinder and the hollow cylinder look similar initially, but over time the TVAC for the hollow cylinder develops a set of nulls at

different frequency bins, until the overall glint slowly vanishes and the end-on elastic responses persist longer than those of the solid cylinder's.

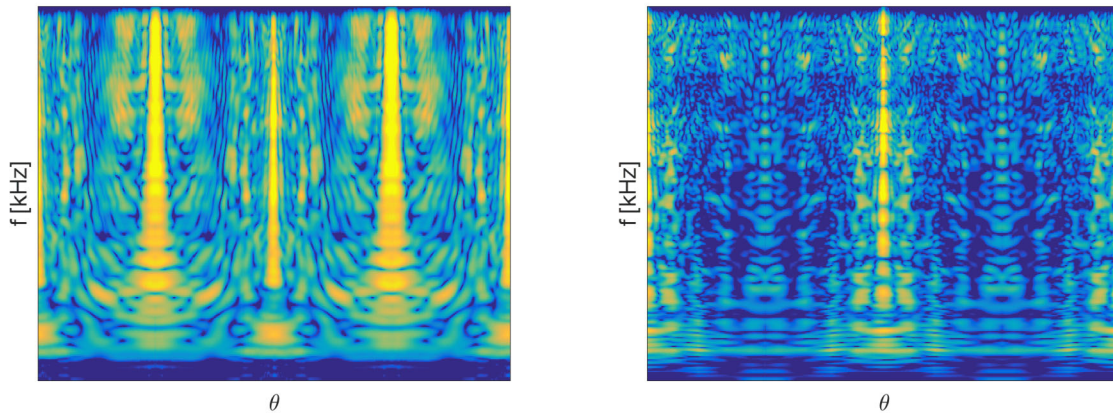


Figure 5 A comparison of Acoustic Colors for a solid Aluminum cylinder (left), and a hollow Aluminum cylinder (right). They are noticeably different, but it is difficult to identify the elastic response from the hollow object

Based on the observation from the TVAC, one way to describe the elastic response and its strength is the depth of the nulls in the spectral pattern. Geometric responses tend to be the first scattering off the object and elastic responses tend to arrive later in time and they consist of multiple scattering of the transmitted waveform from different facets of the same object. Multiple scattering from different object surfaces result in delayed copies of the originally transmitted waveform and they interfere with other to create spectral nulls that develop into deeper nulls over time. The spectral response averaged over the whole response time is seen in Figure 5.

Combining the analyses on domain transformation and utilizing the phase component of these spectral representations, spectral null depth can be measured by taking the derivative of magnitude or phase of the complex spatial spectrum. (c)

(d)

Figure 6 depicts the post-processed magnitude-gradient and phase-gradient.

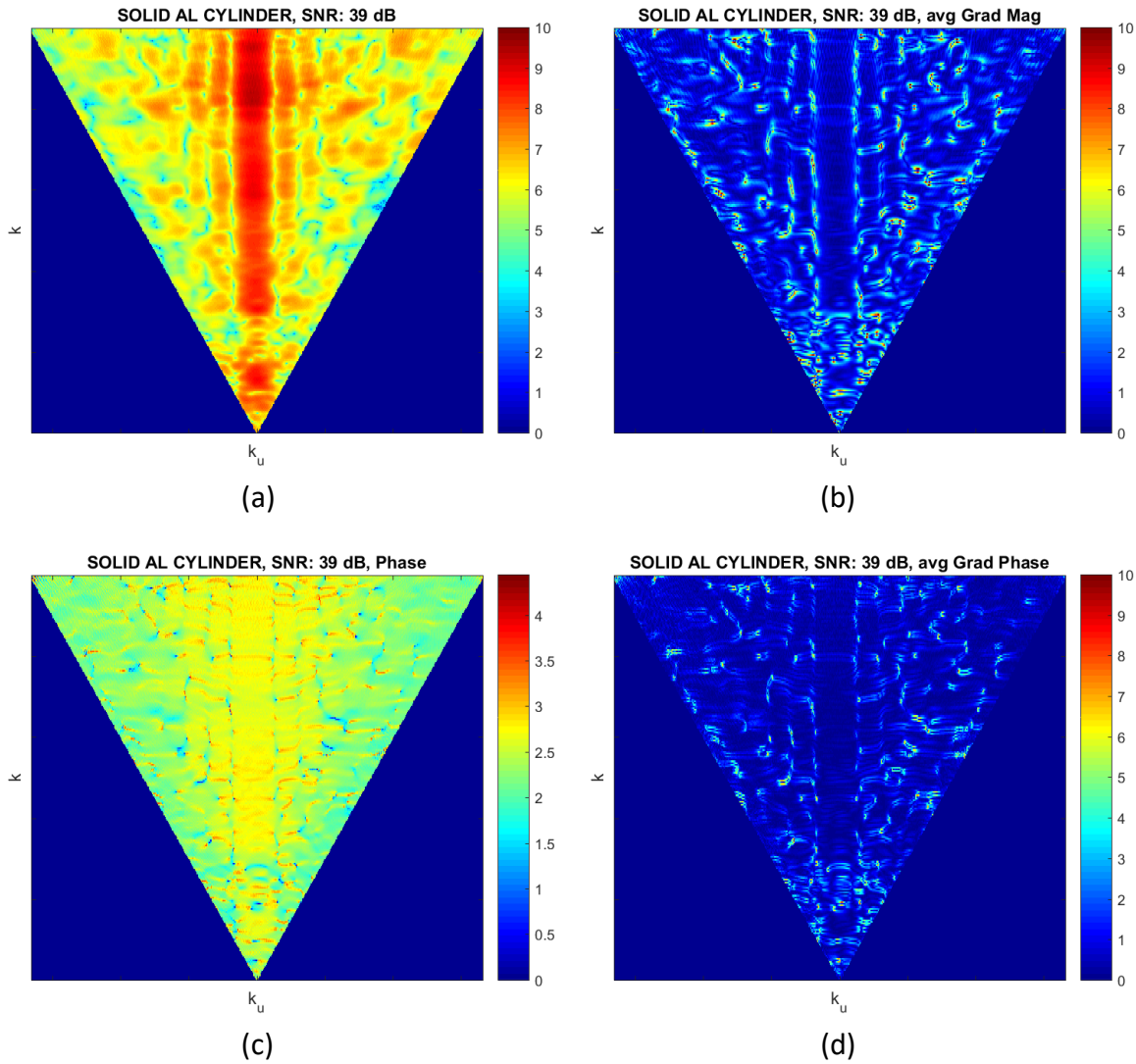


Figure 6 Starting from the complex acoustic color data for a solid aluminum cylinder transformed into (k_u, k) , (a) is the magnitude and (c) is the phase gradient of the complex data. (b) and (d) are the gradient image of (a) and (c), respectively. The gradient image (b) and (d) highlight where the nulls are located and their depth.

Of the four sub-figures in (c)

(d)

Figure 6, (a) and (c) are the magnitude and phase gradient of the complex spatial spectrum of a solid aluminum cylinder in the (k_u, k) domain. The corresponding sub-figures (b) and (d) are the post-processed gradient image of (a) and (c), respectively, highlighting the null locations. These post-processed image are summarized with a statistic measured by taking the average of the post-processed image. We performed an analysis to characterize the sensitivity of this statistic to the external noise level, or equivalently, the signal-to-noise ratio (SNR). The noise is additive Gaussian in the time domain. Our hypothesis is that lower SNR will likely result in

shallower nulls since external noise will fill in the spectral nulls. On the other hand, higher SNR will result in deeper nulls.

Figure 7 and (θ, f)

(b) (k_x, k_y)

(c) (k_u, k)

Figure 8 show how the measured average gradient for various objects changes with SNR. The average gradient generally decreases as SNR increases, and converges when SNR reaches about 35 dB. Objects with inherently complex signatures, e.g., aluminum pipe and aluminum UXO shell, tend to converge at higher values than those of other objects, but at low SNR values they converge around the same value since noise dominates the signal and we used the same type of noise.

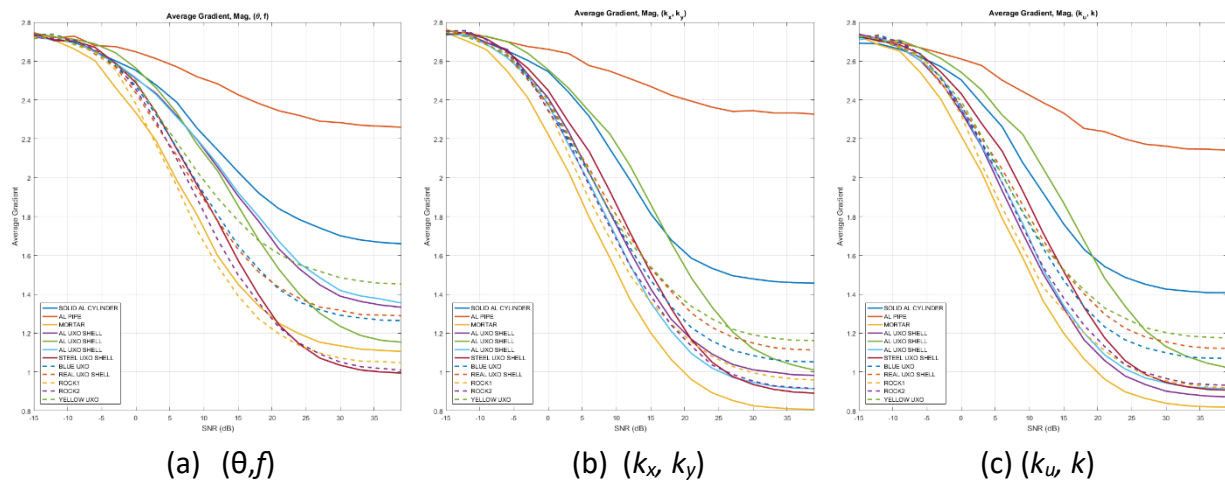


Figure 7 Average gradient of the post-processed null-detection image on the Magnitude of the complex spatial spectrum as SNR increases for the three domains, (ϑ, f) , (k_x, k_y) , and (k_u, k) .

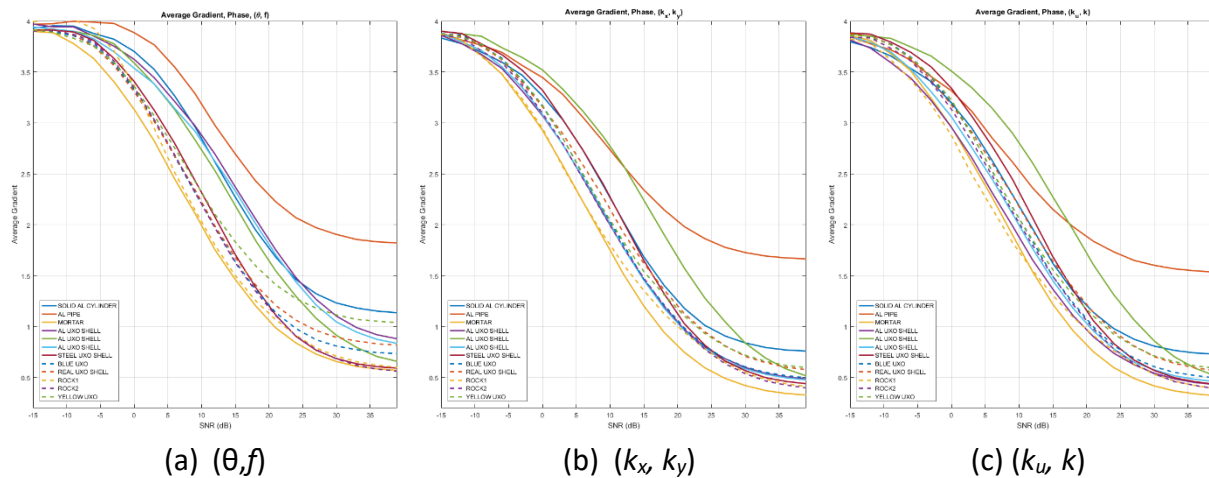


Figure 8 Average gradient of the post-processed null-detection image on the Phase of the complex spatial spectrum as SNR increases for the three domains, (ϑ, f) , (k_x, k_y) , and (k_u, k) .

When comparing magnitude and phase, curves in Figure 8 using the Phase seems to cluster together more than those of Figure 7 using the Magnitude. When comparing across the domains, the curves in (θ, f) are spread out more than the curves in the other two domains. The implication is that when the curves are more clustered together, they are less dependent on the object type and can serve better as an objective measure of SNR. In turn, this implies that average gradient is a reasonable surrogate for SNR and as a quality metric in the spatial spectrum domain. Based in this qualitative assessment, phase of spatial spectrum in the (k_u, k) domain is the most reliable means of estimating the quality of the data.

What opportunities for training and professional development did the project provide?

J. Daniel Park attended and presented at the IEEE Underwater Acoustic Signal Processing (UASP) Workshop held in the Alton Jones campus of University of Rhode Island, October 14-16, 2015. The presentation was entitled “Quality Assessment of Acoustic Color Signatures”

Daniel Cook attended the 172nd meeting of the Acoustical Society of America (ASA) held in Hawaii, November 28 – December 2, 2016. The presentation was entitled, “Quality Assessment of Acoustic Color Signatures,” and it was authored by Daniel Cook, Daniel Park, and Alan Hunter.

J. Daniel Park gave a presentation entitled “Signal processing trade-offs for the representation and quality assessment of acoustic color signatures” at the Acoustics '17 / 173rd meeting of the Acoustical Society of America held in Boston, MA, June 25-29, 2017.

Brett Bissinger gave a presentation entitled “Signal processing trade-offs for the quality assessment of acoustic color signatures” at the 174th meeting of the Acoustical Society of America held in New Orleans, LA, December 4-8, 2017. The presentation was authored by Brett Bissinger and J. Daniel Park.

Wendy Newcomb gave a presentation entitled “Representation trade-offs for the quality assessment of acoustic color signatures” at the 175th meeting of the Acoustical Society of America held in Minneapolis, MN, May 7-11, 2018. The presentation was authored by J. Daniel Park, Wendy Newcomb, and Daniel Cook

How were the results disseminated to communities of interest?

“Nothing to report”

What do you plan to do during the next reporting period to accomplish the goals and objectives?

This is the final report for this program.

Honors: What honors or awards were received under this project in this reporting period?

“Nothing to report”

Technology Transfer

“Nothing to report”

Participants

J. Daniel Park (PI at ARL Penn State)

Students

“Nothing to report”

Products

“Nothing to report”