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Visualizing Hydrophone Data

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Abstract—Underwater noise generated by river, ocean or tidal turbines has the potential to affect fish and marine life. The noise created by the turbine may lead to avoidance, attraction or behavioral modifications. It is thus essential to understand the relationship between various turbine specifications, including design, placement, and operating conditions, and the resulting noise generated by the turbine system to inform design selection and siting decisions. This paper proposes a novel visualization technique to facilitate the evaluation and analysis of acoustic data, demonstrated using experimental data from a study near Iguigig, AK.

Index Terms—Hydrokinetic Turbine, Acoustics, Hydrophone, Visualization

1 Introduction

Hydrokinetic marine turbines have the potential to generate a vast amount of clean, renewable energy. One potential use for hydrokinetic turbines is to serve remote, isolated communities with a single marine or river current turbine. These communities, far removed from any connection to the grid, could then run off this renewable power and be released from their current dependence on imported fossil fuels. However, it is essential to understand the impact of the turbines on their aquatic environment before they are commercially deployed. One important facet of potential impact is the acoustic signature of the turbine. Examining the acoustic behavior of a turbine under different operating conditions allows for a characterization of the possible range of impacts on the established environment. In order to effectively understand and process experimental acoustic data to inform this characterization, however, a flexible, efficient visual platform is required.

This work presents a possible candidate for that visual platform. The interactive visualization proposed explores the attenuation of different frequency bands of the recorded signals in the spatial domain. The visualization allows for viewing multiple signals at a time and comparison between different turbine operating conditions.

The experimental data used to demonstrate this visual platform was collected by Dr. Brian Polagye and Paul Murphy of the University of Washington during the summer of 2014 [2]. Their group monitored a helical cross-flow hydrokinetic turbine operating near Iguigig, AK (USA) to characterize its acoustic signature in the riverine environment. They used drifting spar buoys equipped with hydrophones and GPS loggers to characterize temporal and spatial variability in turbine sound over a range of turbine operating conditions.

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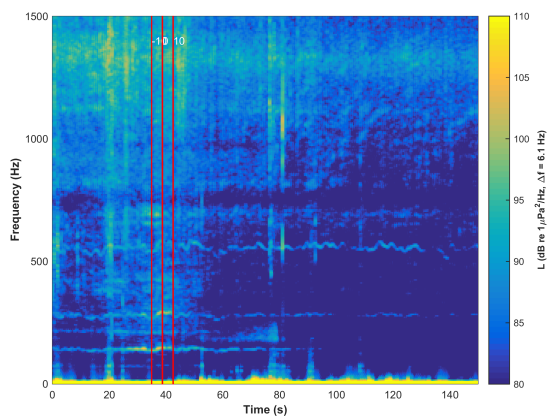


Fig. 1. Spectrogram of a turbine acoustic signal [1].

2 Related Work

Spectrograms are commonly used to represent signals such as sound [4]. An example of a spectrogram for this data is shown in Figure 1 [1]. In this plot, the amplitude of the signal at a specific time and frequency are encoded using color. The sound from the turbine consists of broadband emissions, emitted from the turbine generator, and tones, which are ascribed to the blades and vary in proportion to the turbine rotation rate. The intensity of these sounds attenuate with distance from the turbine. These attributes can be determined from the spectrogram, but the process is neither simple nor extremely accurate.

Occasionally, three-dimensional spectrograms are produced to attempt to facilitate understanding, such as in Figure 2 [3]. These plots encode amplitude with both color and height, in hopes that the redundant encoding will ease the user's cognitive load. Though the plots are

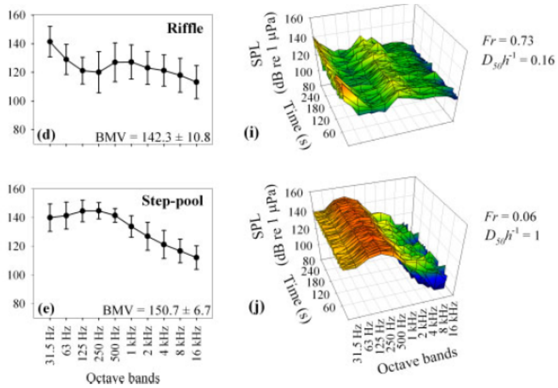


Fig. 2. 3-Dimensional spectrogram of an acoustic signal [3].

perhaps more engaging, they have the same weaknesses as the traditional spectrograms discussed above.

Both spectrogram representations makes it challenging to visualize and quantify the attenuation of the acoustic signal in the spatial domain. Additionally, it is difficult to compare spectrograms between different cases, and presenting a spectrogram for several cases requires a significant amount of space. The visualization presented here attempts to address those problems with a more intuitive, space-efficient platform.

3 Methods

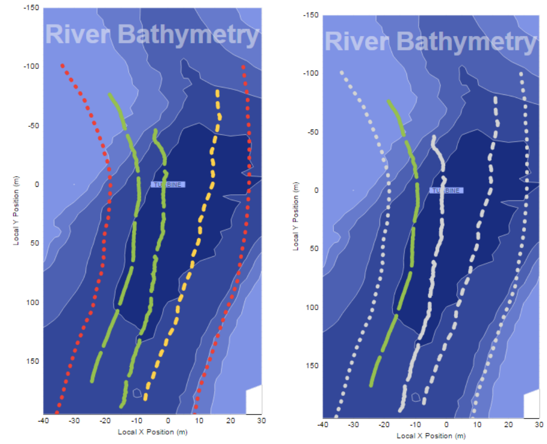
The visualization in this work explores the attenuation of different frequency bands of the recorded signals in the spatial domain for different turbine operating conditions. The visualization is created for experts in the field as a tool to inform design and siting decisions, allowing users to determine if a particular attenuation is affected by the shape and depth of the riverbed, the frequency of the signal, or other conditions. Several separate, dynamically linked images convey the spatial location of the hydrophone, the frequency characteristics of the signal, and how the magnitude of the recorded pressures change with distance from the turbine.

3.1 Geo-reference window

The left-most and most visually arresting on page load is the georeferencing window, shown in Figure 3(a). This window displays the position of the turbine and path of each hydrophone run, superimposed onto the river bathymetry. River depth is encoded in shades of blue, while the turbine operating condition of each run is double encoded to the color and line-type of the path to help with continuity across windows. Mousing over a run will pop out a tooltip that displays the metadata of the run, including date and time of the drift, the turbine operating condition, and any extra notes (i.e, if there was a sea plane or a fishing vessel in the area). One run or several can be selected as active and the rest will gray out, allowing the user to follow and compare runs between windows. This is demonstrated in Figure 3(b).

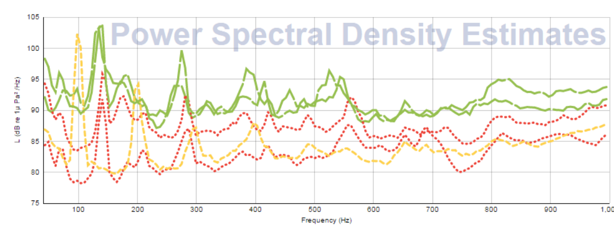
3.2 Frequency content window

The top-most window in the visual display contains the power spectral density estimates, or the frequency content of the signal, shown in Figure 4. This window contains the same frequency information as the original spectrogram, but in a two-dimensional view to facilitate comparisons between multiple runs. A brushing tool allows the user to select a frequency range to apply a band pass filter, allowing the user to investigate specific tones attributed to the turbine blades. The results of that filter are displayed as amplitude profiles in the spatial content windows below. The line color and type of each run are carried over from the geo-referencing window for continuity, as is the highlighting for selected runs.

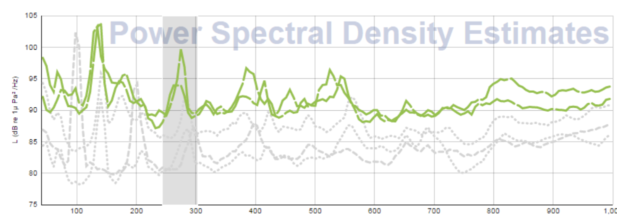


(a) Default view (b) One run selected

Fig. 3. Bathymetry and geo-referencing window.

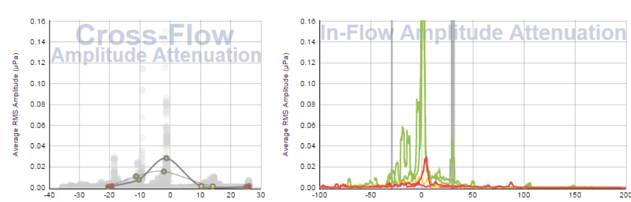


(a) Default view

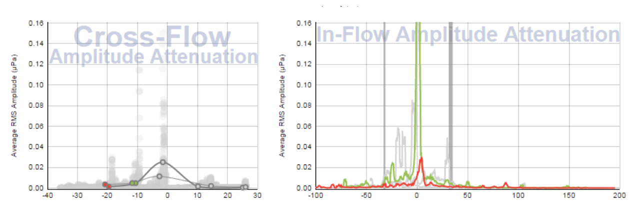


(b) Two runs and a frequency band filter selected

Fig. 4. Frequency content window.



(a) Default view for a selected frequency filter



(b) Two runs selected for the same frequency filter

Fig. 5. Cross-flow and in-flow spatial content windows.

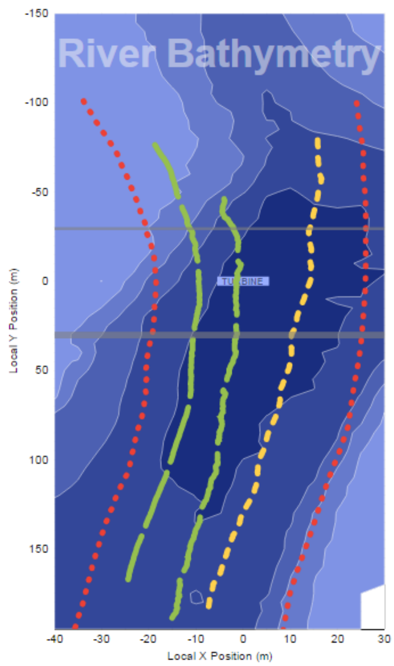


Fig. 6. Up- and down-stream position lines reflect on bathymetry plot.

3.3 Spatial content windows

The lower windows display the spatial content that is contained roughly in the original spectrogram. However, a spectrogram axis generally encodes time, not space. While it is true that in this case, the drift runs do move monotonically down the river and thus spatial location and run time are strongly correlated, this may not always be true. As the relevant question relates to the distance from the turbine at which specific tones can be distinguished, a spatial variable is preferable to run time. The spatial content windows display amplitude attenuation both in the cross-flow (left) and in-flow (right) directions, as shown in Figure 5. Again, the line color and highlighted status of each run is carried over from the other windows (though selecting the highlighted runs can be performed from any window). The in-flow spatial content window also contains a pair of position lines equidistant from the turbine position, or $x = 0$. These lines are controlled by mouse-over, and in turn control the cross-flow selection. The thick line consistently represents the downstream position, while the thin line represents the upstream position. They are also echoed in the geo-referencing window, to allow comparisons involving river depth. This is shown in Figure 6. These position lines allow the comparison of the up-stream and down-stream profile of the attenuating acoustic signal.

4 Results

The interactive visualization allows users to explore the frequency characteristics and propagation of turbine sound within the riverine environment. The visualization improves over the more traditional representation, a spectrogram, by encoding sound amplitude as position instead of color. This simplifies the cognitive tasks of identifying trends and comparing values. Multiple floats can be displayed at a time because the data representation is two dimensional. This significantly reduces the space needed to display the information, as well as the effort required to compare the frequency and spatial characteristics between floats. This reduction is measured in relation to the task of comparing multiple spectrograms, which requires scanning between images and relies on the users working memory.

The chosen views (spatial, spectral content, and signal amplitude) decompose the complex data into manageable chunks that help to provide insight into the interaction among the different data dimensions. Each view provides a different avenue for comparing the floats and each of these comparisons are meaningful for the range of tasks previously identified. These tasks all revolve around the idea of sound intensity and propagation, and the multiple views aid in the users understanding of the specific attributes that affect these parameters.

4.1 Running times

The visualization takes approximately five seconds to load from a github pages site. A majority of this time can be attributed to waiting for a server response (time-to-first-byte). Filtering the in-flow and cross-flow amplitude plots by brushing takes roughly five to six seconds. Local versions of the visualization are more responsive, however optimizing the method that the code uses to load and store data would also improve over the current performance. This optimization would be required before implementing larger datasets. A loading screen could be added if these times were to increase significantly.

5 Discussion

To determine the efficacy of the visualization, feedback was solicited from a group of engineering graduate students, from attendants of a poster information session, and from researchers who study marine turbines and their ecological affects at the University of Washington.

5.1 Informal user study

As an informal study, several graduate engineering students were asked to complete three representative tasks using both typical spectrograms and the proposed interactive visualization. The two visualizations presented to the participants are shown in Figure 7. The tasks were focused on comparing two hydrophone floats, one under free-wheel (i.e. under no turbine resistance) and another under modest resistance (4.9 ohms). The participants were asked to:

1. Estimate the frequency of the tones produced by the turbine,
2. Determine which signal had a higher overall broadband amplitude,
3. Determine which signals major tone attenuated to half its peak value more quickly.

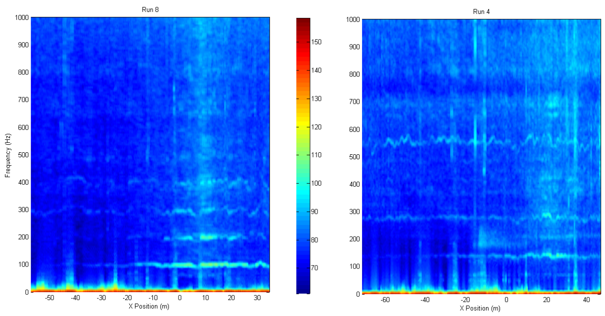
Although the participants had no prior experience reading hydrophone data (and were thus not the target audience for the interactive tool), their insights were valuable in terms of a baseline assessment of the proposed interactive visualization.

Overall the participants were able to estimate the frequencies of the tones produced by the turbine and discern the difference in tone between the two floats using either method, although most of them mentioned a preference for the interactive visualization. Half of the participants were able to discern which signal had a higher broadband noise using the spectrogram, while all of the participants were able to make this distinction using the interactive tool. Additionally, the participants felt more comfortable comparing the attenuation of the signal using the interactive tool. The users methodology when using the spectrogram involved distinguishing almost perceptually indistinguishable colors in a continuous color bar.

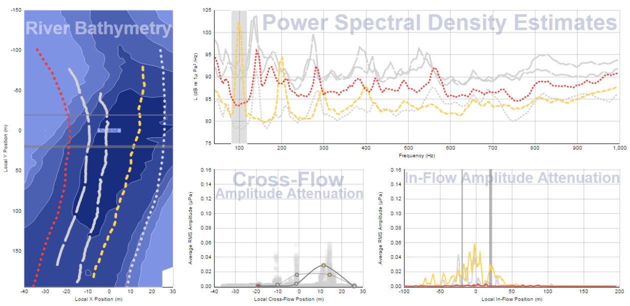
The major feedback from the participants was that additional values on the charts axes or axes with a greater number of tick marks would make it easier to estimate specific values. Additionally users were interested in more mouse-over tooltips and the ability to zoom or rescale the axis of the amplitude plots. Because they were trying to compare two runs, the participants also identified a desire to select multiple runs to highlight on the screen.

5.2 Poster session feedback

Attendants of the poster information session provided useful feedback, ranging from the ease of use of the visualization to additional items that would be interesting to see implemented in the final version. One attendant mentioned that it would be interesting to hear the filtered sound for identification of the different tones and to determine whether the sound came from the turbine or an outside source (like a fishing vessel).



(a) Spectrogram comparison for user study



(b) Visualization comparison for user study

Fig. 7. User study content.

5.3 Feedback from research partners

Unfortunately, our partners in the field are, at the moment, actually in the field and not accessible for comment. We look forward to hearing their feedback and opinions.

5.4 Incorporating feedback

After receiving feedback from users and thinking critically about the types of tasks that were aided by the interactive visualization, two minor changes were made to improve user performance. Selection of multiple runs to aid in comparison was implemented. This change reduced the load on the users working memory and was deemed of high importance for the effectiveness of the tool. In addition, the axes labels were improved by using minor divisions. This improvement was meant to decrease the users cognitive effort in making estimations.

6 Future Work

The current visualization allows the user to visually identify the specific frequencies recorded during different hydrophone runs and allows the user to estimate the propagation of the signal in the riverine environment. In order to make this tool more robust and useful to researchers several areas were identified as particularly important for further improvements.

6.1 Additional interaction for handling large datasets

Currently the interaction is designed around having a small number (less than 10) of hydrophone runs to demonstrate the visualization concept. If this tool were implemented in practice, the user would likely want to have an entire suite of runs loaded and make comparisons across different operating conditions. In order to aid in this, additional selection/filtering methods (like dropdowns or checkboxes) for different operating condition, weather, date, river condition, etc. should be included. By only displaying a subset of the data, the current encodings would remain effective.

6.2 Data processing for field testing

The interaction was built using processed data from field recordings. Future work would include adding signal processing and upload capabilities to allow for pseudo real-time acquisition of the data. In this fashion, researchers could log data as it was collected and be able to quickly identify trends and outliers. This process was out of the scope of this paper, because it would likely require pushing computations to the local machine and writing format specific code to parse and link multiple data sources (i.e. hydrophone and GPS logs).

6.3 Attenuation models and river depth

One of the major questions that the visualization tries to address is how different frequency bands attenuate in the riverine system. Because this relates to the bathymetry of the river, one area of additional refinement would be to include the depth of the river underneath the in-flow and cross-flow amplitude plots with spatial x-axes. This may make some of the variations in amplitude more sensible, since they are potentially related to the depth of the river at that location. Adding standard attenuation models to the amplitude plots is another potential improvement that may aid in quickly identifying and comparing the propagation of specific frequencies.

Acknowledgments

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