International Student Challenge Problem in Acoustic Signal Processing 2024

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An initiative of the Acoustical Society of America (ASA) Technical Committee on Signal Processing in Acoustics (TCSPA) is to pose international student challenge problems in the discipline of acoustic signal processing (Ferguson and Culver, 2014; Ferguson et al., 2019, 2023). At the 185th meeting of the ASA (December 4-8, 2023, in Sydney, Australia), the TCSPA proposed posing a problem for 2024 on the localization of free-ranging echolocating dolphins that would appeal not only to acoustic signal processors but also to a broader group of students such as marine bioacousticians.

The International Student Challenge Problem for 2024 involves the student (or team of students) processing real acoustic data to extract information about sources from the sounds that they project. Specifically, the sources of sound are free-ranging echolocating dolphins, where students have the opportunity to address aspects of Au's observation (1993, p. 271): "Our perception of how dolphins utilize their sonar in the wild is based on extrapolation of knowledge observed in 'laboratory' experiments — we do not have the foggiest idea of how dolphins utilize their sonar in a natural environment."

For the present problem, the acoustic sensors are three hydrophones (H1, H2, and H3) located 1 m above the sea floor in water 20 m deep. The hydrophones are distributed along a straight line, with a separation distance of 14 m between adjacent hydrophones (i.e., the uniform interelement spacing of the three-element horizontal line array is 14 m). Hydrophone H2 (the middle sensor) is at the center of the array and is referred to as the reference hydrophone located at the origin. The array axis, which extends from H1 to H3, is oriented in a west-east direction, i.e., H1 is to the west of H2 (the origin), and H3 is to the east. The hydrophone outputs are all sampled for 8.2 s at the rate of 250,000 samples/s (i.e., the sampling period is 4 μs). The digital time series of sampled data for each hydrophone is recorded in Waveform Audio File Format (WAV). The element-level data files are HYD1.wav, HYD2.wav, and HYD3.wav, and they can be downloaded as .wav files at acousticstoday.org/asa-student-challenge-2024.

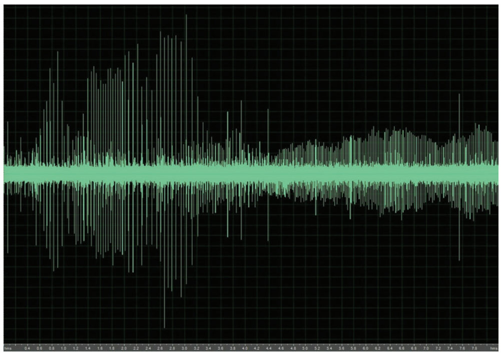

Figure 1. *Variation with time of the output of the middle hydrophone: H2.*

Task 1

The variation with time of the output of H2 (HYD2.wav) is shown in **Figure 1**. Two sequences (or trains) of dolphin echolocation clicks are evident: one sequence starts near the beginning (emitted by dolphin A) and the other (by dolphin B) starts near the middle. Other extraneous impulses observed in the data file can, in the main, be attributed to the snaps of shrimp. The first task is to detect the echolocation clicks and record the time of arrival (TOA) of the peak pressure (maximum amplitude) of each click at H2 for click sequence A emitted by dolphin A and then repeat for click sequence B.

(1) In microseconds, what is the uncertainty in your TOA measurement of a click's maximum amplitude (or peak pressure)?

(2) For each click sequence, plot the variation with click number of the interclick interval (ICI), i.e., the time difference of arrival of consecutive clicks or the time interval (time span) between successive click peak pressures. Calculate the mean and standard deviation

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of the ICI for each click sequence along with the total number of clicks (N).

(3) For technological sonars, the pulse repetition frequency is constant, i.e., the time interval between sonar pulse transmissions is constant. Is this the case for the echolocation biosonars of dolphins A and B?

Task 2

The next task involves locating the positions of the sources of the clicks, i.e., localizing the sound projectors of the echolocating dolphins. This task requires associating each click received on H2 with its counterparts in the sequences received on the adjacent hydrophones H1 and H3. Intuitively, the *difference* in a click's arrival times, i.e., the differential time of arrival (DTOA), at a pair of hydrophones has directional information. For instance, when the DTOA is zero, (i.e., the TOAs are the same), the source is in a broadside direction (i.e., at right angles to the array axis). Similarly, for a pair of adjacent hydrophones separated by a distance $d = 14$ m, if the DTOA has a maximum value of $+d/c = 14/1520 \approx 9.2$ ms (where $c = 1520$ m/s is the isospeed of sound travel in the underwater medium for the present experiment and 'ms' denotes milliseconds), then the source is in an end-fire direction (i.e., in the direction of the array axis). When the DTOA has a minimum value of $-d/c$, the source is in the other end-fire direction. The source bearing (β) is measured in a counterclockwise direction with respect to the (east-west) array axis, e.g., $\beta = 0°$ is due east and $\beta = 90°$ is due north. Whereas only one pair of hydrophones is required to estimate the source bearing (i.e., the angle of the source relative to the array axis), two adjacent pairs are required to estimate the source range. The range (R) is measured with respect to the origin, i.e., the position of the middle hydrophone H2.

(1) For dolphin A, plot the variation with click number of the source bearing. Calculate the mean and standard deviation of dolphin A's bearing estimates for the echolocation click sequence along with the total number of clicks (N). Repeat for dolphin B. Comment on how well your estimates localize the direction of each echolocating dolphin. Do your bearing estimates indicate that the source is in motion? Are you able to estimate the *precision* of your bearing estimation method, where the term *precision* is used to indicate the closeness with which the measurements agree with one another quite independently of any systematic error involved; the precision is limited by random errors and excludes any systematic (or bias) errors.

(2) For dolphin A, plot the variation with click number of source range. Calculate the mean and standard deviation of dolphin A's range estimates for the echolocation click sequence along with the total number of clicks (N). Repeat for dolphin B. Comment on how well your estimates localize the range of each echolocating dolphin.

Your solution should detail your approach, signal-processing methods, and reasoning to solve the problem as well as your best estimates for the above parameters.

The deadline for student submissions is November 15, 2024. Submit your solutions along with your contact details and proof of student status to asa@aip.org with the subject line Entry for International Student Challenge Problem in Acoustic Signal Processing 2024. The finalists and prize winners (monetary prizes for winning entries: first place, \$600; second, \$400; and third, \$300) will be announced by November 30, 2024.

References

Au, W. W. L. (1993). *The Sonar of Dolphins*. Springer-Verlag, New York, NY. 1993.

Ferguson, B. G., and Culver, R. L. (2014). International student challenge problem in acoustic signal processing. *Acoustics Today* 10(2), 26-29.

Ferguson, B. G., Culver, R. L., and Gemba, K. L. (2019). International student challenge problem in acoustic signal processing. *Acoustics Today* 15(1), 71-73.

Ferguson, B. G., Culver, R. L., and Gemba, K. L. (2023). International student challenge problem in acoustic signal processing. *Acoustics Today* 19(1), 59.

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Explore Acoustics Through ASA Publications' Podcasts

Kat Setzer

Whenever I mention the Acoustical Society of America (ASA) publication's podcast, *Across Acoustics* (acrossacoustics.buzzsprout.com), to someone in the Society, I usually get one of two responses: "I love it!" or "ASA has a podcast?" Sadly, the latter response is still all too common, even though we have published over 50 episodes and have surpassed 20,000 downloads. Thus, my goal with this article is to introduce more people to my pet project. Hopefully, you will enjoy listening to it as much as I have enjoyed recording it!

Across Acoustics started in 2021 and currently publishes two episodes per month. The podcast covers material from all four of the ASA's publications: *The Journal of the Acoustical Society of America* (*JASA*), *JASA Express Letters* (*JASA-EL*), *Proceedings of Meetings on Acoustics* (*POMA*), and, of course, *Acoustics Today* (*AT*). Guests on the show have included ASA Gold Medal winners, student researchers, *JASA* guest editors, and other members of the acoustics community representing research institutions and other organizations all over the world. Our aim is to share interviews that are easy to understand, even if the research is not in your field, so you can find out more about what's happening in the world of microphones, supersonic jets, common shrews, lung ultrasound, or any of the many topics covered in our publications. And much like with articles in *AT*, we hope that the podcast content will be appealing and accessible to those outside of the Society as well, so you can share with the nonacousticians in your life!

Below are some of our most listened-to episodes, representing the diversity of topics that we cover on the show. I have also included QR codes for readers who would prefer to listen to episodes on their mobile devices. The next time you are driving to work or doing chores around the house, pop on one of these episodes to make your experience a bit more fun and educational!

What Is Silence?

This highly downloaded episode (see bit.ly/AA-silence) takes a bit of a philosophical bent and will likely appeal to most folks who are interested in the study of sound. In it, ASA Gold Medal recipient William Yost (Arizona State University, Tempe) talks about how we define sound, how perception impacts our understanding of sound, and whether silence is simply the absence of sound or something else.

What Is an Acoustic Metamaterial?

Metamaterials have been a hot topic in the acoustics community since the late 1990s (see bit.ly/4bgmUvv), but there's no consensus among researchers as to what a metamaterial actually is or when they first came about. Christina Naify (University of Texas at Austin), chair of the Structural Acoustics and Vibration Technical Committee, took a deep dive into the literature about metamaterials and then posed the question to an audience of researchers in a session at the ASA conference in Chicago, IL. In this episode (see bit.ly/aa-acoustic-metamaterials), we talk about what came up in that discussion.

Deep Faking Room Impulse Responses

It's not always feasible to measure the entirety of a sound field. Instead, scientists use models to come up with a best guess of the missing pieces. In this episode (see bit.ly/AA-room-impulse-responses), we talk with Efren Fernandez-Grande and Xenofon Karakonstantis (Technical University of Denmark, Kongens Lyngby) about their new machine learning method to reconstruct sound fields.

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Conservation Bioacoustics: Listening to the Heartbeat of the Earth

Recent advances in technology have allowed scientists to gather larger quantities of acoustic data from locations more remote than ever before. As a result, the study of animal sounds can be used to inform species or habitat conservation and natural resource management practices in new and exciting ways. In this episode (see bit.ly/AA-cons-bioacoustics), we talk to Aaron Rice (Cornell University, Ithaca, New York) about how acoustics can be used to advance conservation efforts as well as how people outside large research universities can take part in efforts to help save the planet with science. (This episode stems from an article Rice wrote for *AT* (see doi.org/10.1121/AT.2023.19.3.46).

Modeling of Musical Instruments

How does a piano string compare to an ideal physicist's string? Are there equations that describe the sound a recorder produces? Can the quality of an instrument be quantified? In this episode (see bit.ly/AA-modeling-instruments), we talk to one of the editors of the *JASA* Special Issue on Modeling of Musical Instruments (see bit.ly/4as4RkD), Nicholas Giardano (Auburn University, Auburn, Alabama), about the wide variety of research efforts regarding analytical and computational techniques to model musical instruments, and how these techniques can help both instrument makers and musicians.

Reconsidering Classic Ideas in Speech Communication

Most researchers know the seminal articles that have impacted their field. Sometimes, though, the research in those articles can get misinterpreted or exaggerated, and those misunderstandings can take hold and reappear year after year. In this episode (see bit.ly/AA-speech-comm), we talk to the editors of the *JASA* Special Issue on Reconsidering Classic Ideas in Speech Communication (see bit.ly/4arfzrJ), Matthew Winn (University of Minnesota, Minneapolis), Richard Wright (University of Washington, Seattle), and Benjamin Tucker (Northern Arizona University, Flagstaff), about ideas in speech communication that were reexamined in the Special Issue.

This is only a handful of our many episodes, which span the breadth of the ASA's areas of study. I hope after listening to some of these, you will be enticed to explore our archives and find more that pique your interest! Plus, the podcast is available on the major podcast platforms, so you can subscribe and have the latest episode delivered directly to your mobile device.

And more good news: Going forward, *AT* will be including links to related episodes with every article (and QR codes, so you can just scan with your phone and listen!). Keep an eye out for insets with related content in the articles of this and coming issues of *AT*.

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