International Student Challenge Problem in Acoustic Signal Processing 2024

Brian G. Ferguson, R. Lee Culver, and Kay L. Gemba

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.

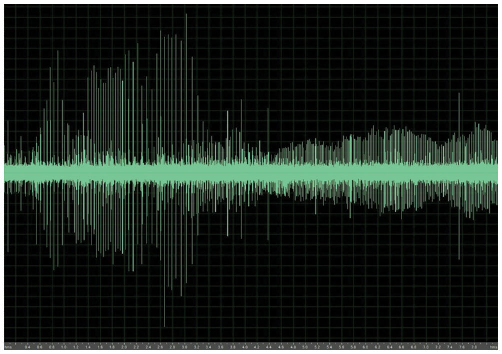

Figure 1. *Variation with time of the output of the middle hydrophone: H2.*

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., β = 0° is due east and β = 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.

Contact Information

Brian G. Ferguson Brian.Ferguson@defence.gov.au
Defence Science and Technology Group Sydney
Department of Defence
Locked Bag 7005
Liverpool, New South Wales 1871, Australia

R. Lee Culver r.lee.culver@gmail.com
Applied Research Laboratory
Pennsylvania State University
University Park, Pennsylvania 16802, USA

Kay L. Gemba kay.gemba@nps.edu
Naval Postgraduate School
1 University Circle
Monterey, California 93943, USA