ECHOLOCATION

Phased arrays & the Egyptian fruit bat

PLoS Biol. **15**, e2003148 (2017)

Adaptive sampling is a key strategy in both the animal world and human engineering. Much like sonar, echolocating animals like bats and toothed whales send out sound waves in specific directions, shining an “acoustic flashlight” that guides them in foraging or navigation. The animal can sweep the beam through an area of interest, analyze the returning echoes, and then shift the beam’s direction to get more information.

“When you’re in a cluttered environment, you don’t want to send out sound in all directions because you get echoes back from everywhere. If you focus your sound beam going out, you have less interference from other directions,” says Wu-Jung Lee, a research associate at the Applied Physics Lab at University of Washington.

Most bats visibly move their heads or facial appendages to change the direction of the sound beam, but not the Egyptian fruit bat. The animals produce a pair of beams with alternating directions, but “no one knows how they do it, because they don’t move their head that much while changing beam directions,” says Lee, who published a study combining physics modeling and experimental results to investigate the mechanism. The paper appeared in *PloS Biology* on December 15, 2017.

To measure the direction and shape of echolocation beams, previous experiments had set up linear or two-dimensional arrays of microphones on the walls of a flight room, or in the wild. But the shape of the Egyptian fruit bat’s mouth inspired Lee’s to take a different experimental approach. She predicted that the beam produced by the bat’s mouth would be vertically-elongated. That is, the beam would be an ellipse higher than it is wide. “That’s a physics-based prediction,” says Lee.

Such a beam would fan out beyond an array set up on a wall, encompassing the floor and ceiling as well. So Lee set up a 3D array, populating the walls, ceiling, and

Head stage placement. Credit: Image adapted from *PLoS Biol.* **15**, e2003148 (2017)

floor with ultrasonic microphones, which allowed her to pinpoint the beams. A head stage on the bat with three circular reflective beads allowed infrared video cameras to track the orientation of the animal’s head. As the bat produced two beams in rapid succession by clicking its tongue, the microphones picked up the intensity and frequency of the signal at different locations, while the video cameras captured the bat’s position in space.

The experiment produced a surprise. The bat broadcast a wide range of sound frequencies in each beam, as expected from previous observations, but it seemed to be changing the direction of the beam across frequencies. Lower frequency sounds were directed towards either side of the animal, while higher frequency elements of the beam were more concentrated in front of it. No such pattern had been observed in any other echolocating animal, and that gave Lee pause. The microphone array system was new, and she worried that the experimental setup wasn’t operating correctly. So she tested the system on another species of bat with well-known patterns, and “everything looked okay,” says Lee.

The results were a puzzle, because they didn’t fit with the physical model used to explain how other oral-emitting bats, dolphins and whales produce their beams.

It turned out that the history of radar may afford the answer. In the early 20th century, scientists developed the phased array technology to steer the radar signal direction while keeping the machinery stationary. The method relied on manipulating the phase of the transmitted signal at each radiating element, so that the combined radar beam points in a specific direction. A computer can rapidly change the phase information to make rapid beam sweeps, while the array remains still.

One class of phased array is designed such that the radar or sonar beam points to different directions at different frequencies, just like the experimental results. That made Lee wonder if the bats were doing something similar. She consulted a computed tomography (CT) scan of the bat’s head, and then used that to construct a computer model to see if it was capable of producing a similar effect. The model reproduced the beam patterns that they observed during the bat’s flight, suggesting that her idea could be correct.

The study isn’t proof positive. Dr. Lee hopes to employ a high-speed x-ray scanner to examine the specific movements of the bat’s tongue within the mouth. “We can potentially improve the model,” she says.

The work represents a contrast from using biology as a model for solving engineering problems. “We’re going the other way around. We learn a lot about animals by looking at what we know from physics or signal processing, and trying to figure out what the animal is doing. We’re approaching an interesting point of time where we’ve started to know enough about the animal that we can go in the other direction. We might be able to do bio-inspired design,” says Lee.

Jim Kling

Published online: 25 February 2018
<https://doi.org/10.1038/s41684-018-0010-2>