Investigating the Impact of Biomimetic Pinna Shape Variations on Clutter Echoes Received from Natural Environments

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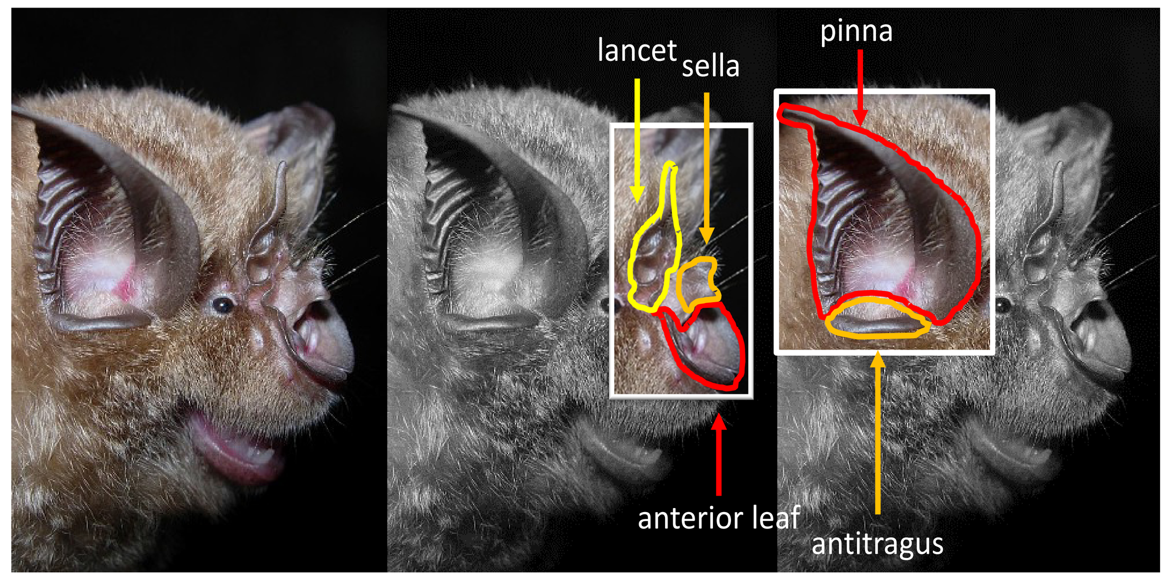
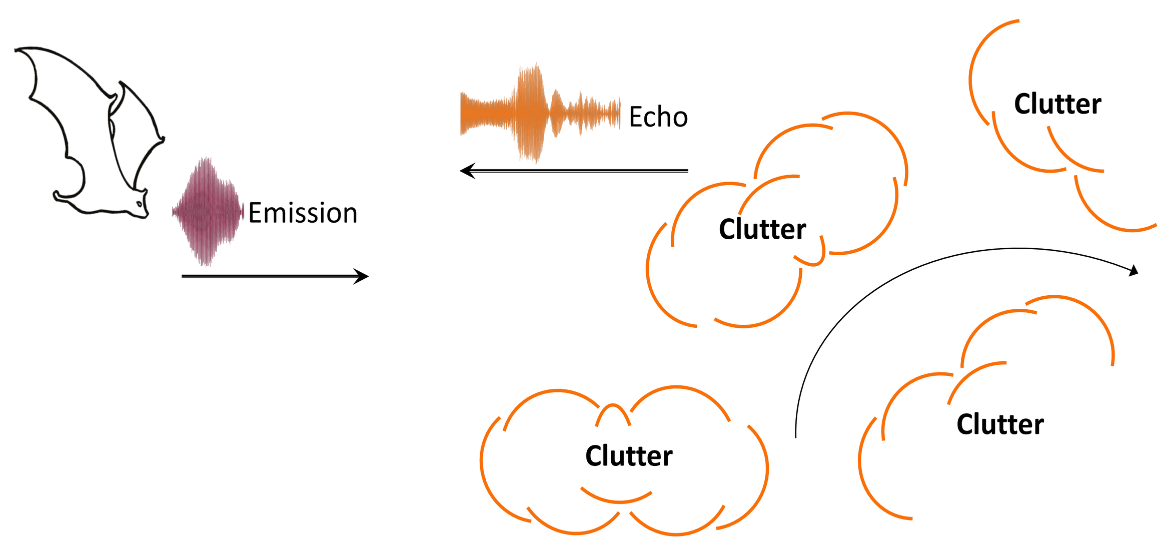
Background



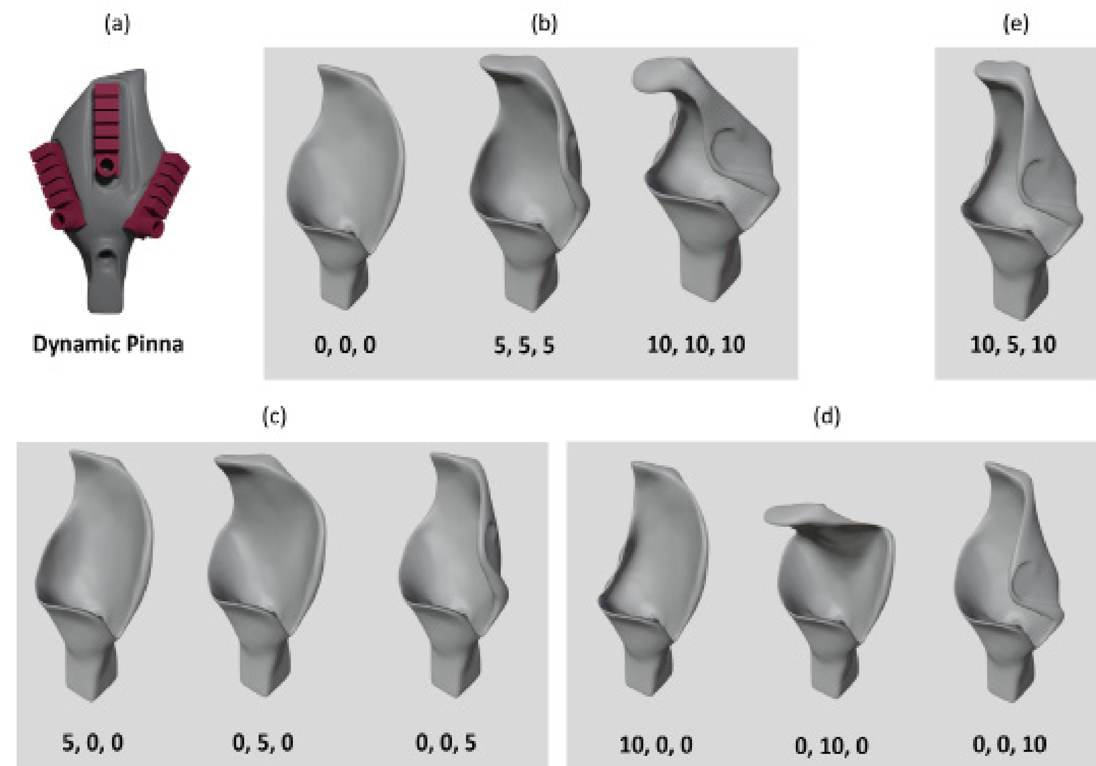
- Bats have achieved remarkable evolutionary success and are known for their echolocation ability.
- Horseshoe bats (rhinolophids) are among bat species that dynamically deform their reception baffles (pinnae) and emission baffles (noseleaves) during signal reception and emission.
- Many bat species live in densely vegetated habitats and hence routinely navigate in narrow gaps between foliage where most of their biosonar returns are clutter echoes from foliage. Nevertheless, they can find their way by relying on sonar as their principal mode for sensing the environment.

Objective

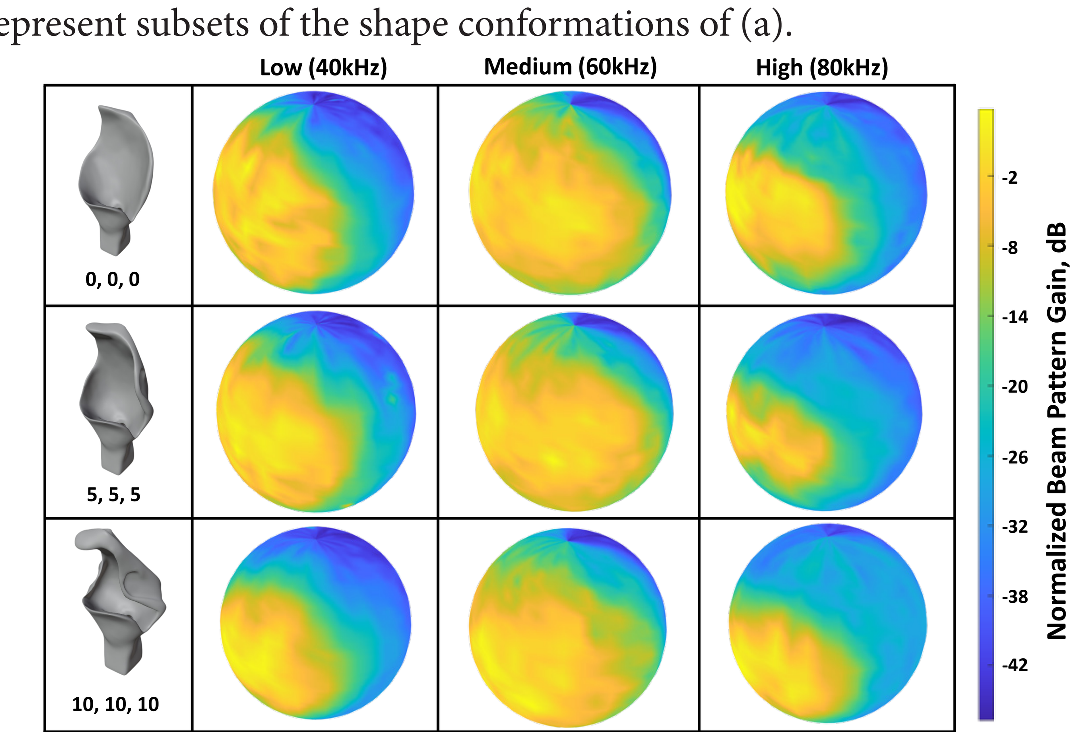


- Bat species navigating dense vegetation based on biosonar have to obtain the necessary sensory information from "clutter echoes", i.e., echoes that are superpositions of contributions from many reflecting facets (e.g., leaves) and hence have highly unpredictable waveforms.
- Prior results have suggested that pinna motions could aid in direction-finding tasks based on deterministic echo patterns.
- This raises the question whether varying pinna shapes could also have a function significance for challenging biosonar tasks performed on clutter echoes.
- As a first, task-independent step to test this hypothesis it has been investigated whether different pinna shapes have a consistent effect on clutter echoes despite the random nature of these signals.

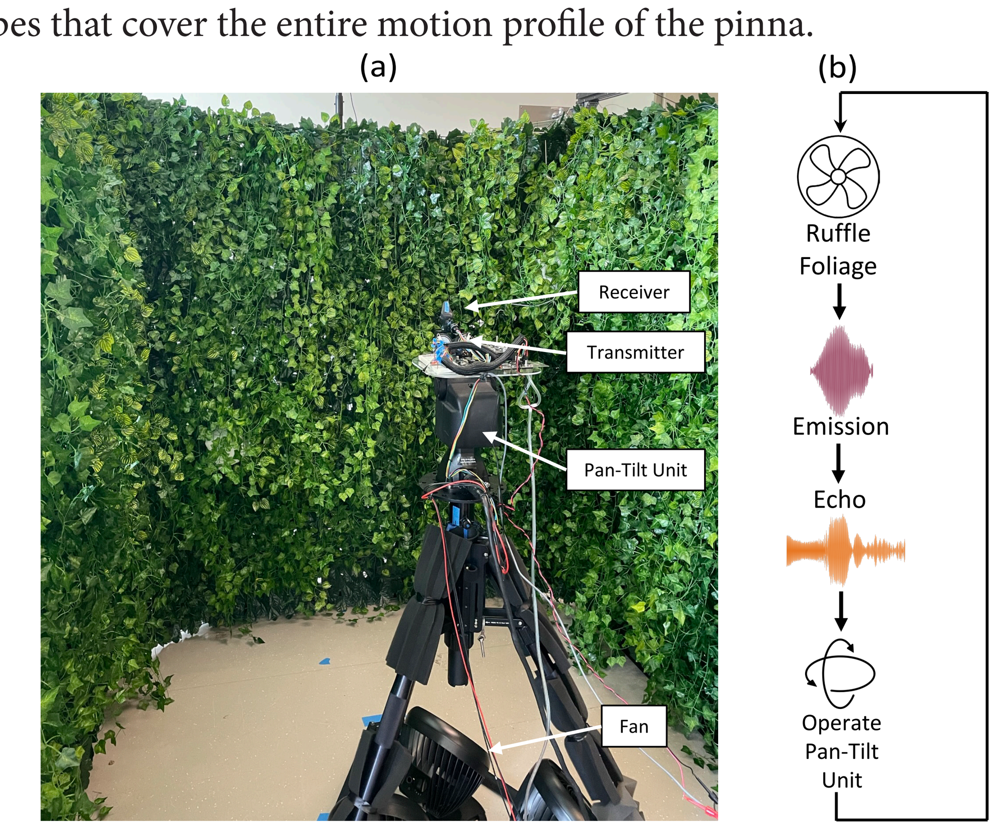
Experimental Setup



A three-actuator dynamic bat-pinna model was developed (a). From this, ten discrete static deformations were selected to model pinna motions a bat might make in a natural environment. Subfigures (b), (c), (d), and (e) represent subsets of the shape conformations of (a).

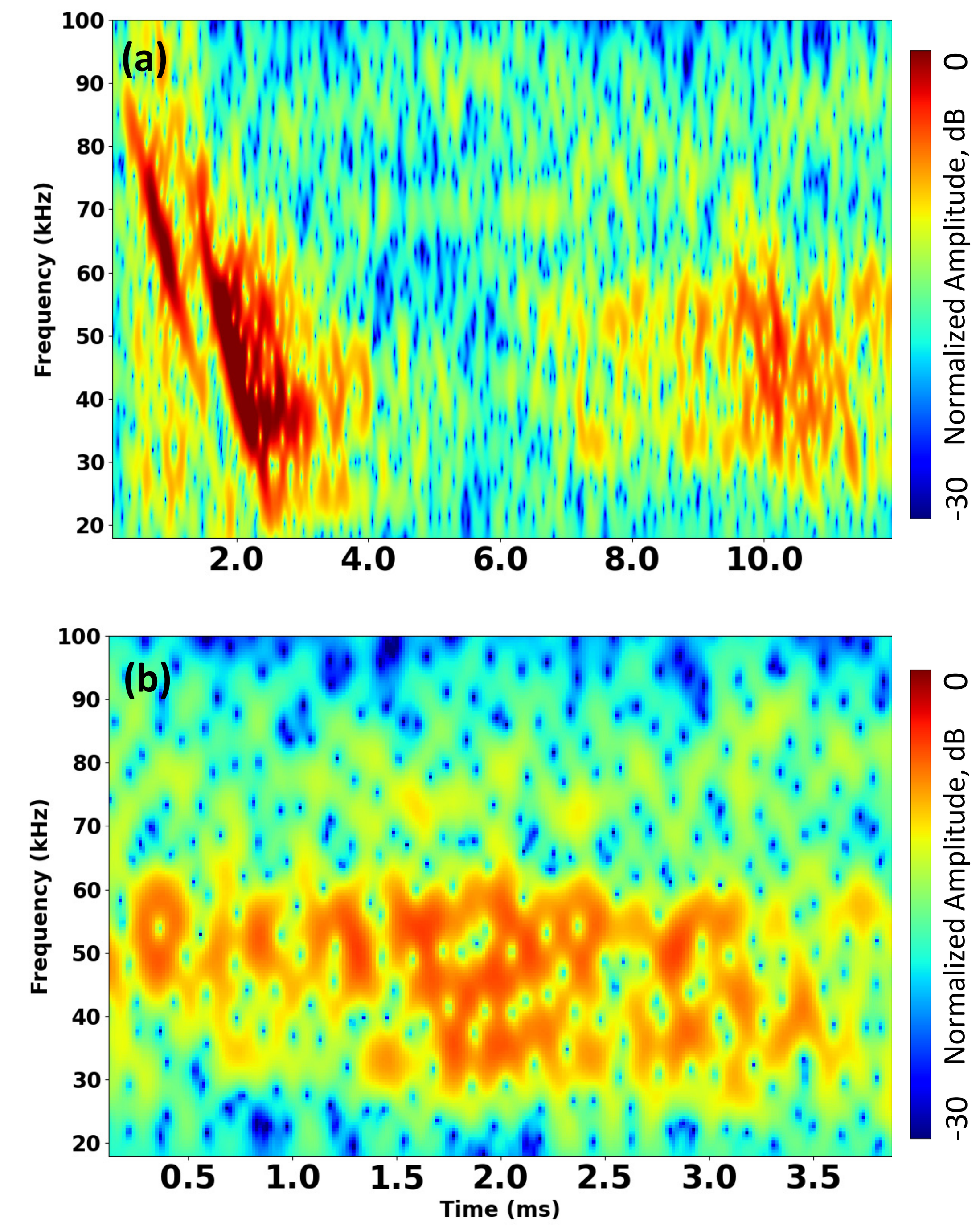


Each receiver was characterized with its respective beampattern at different frequencies. Shown are the characterizations of three discrete pinna shapes that cover the entire motion profile of the pinna.

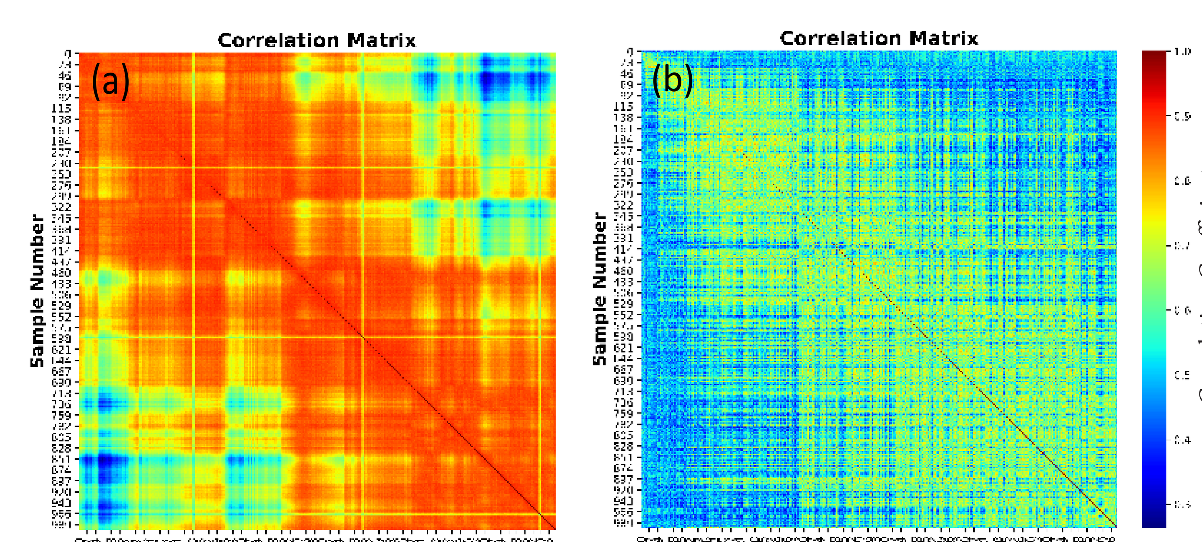


Custom data collection setup used for the research (a) and control scheme for the experiments (b). Between each echo reception, fans were operated to ensure that the artificial foliage different from echo to echo.

Data Analysis

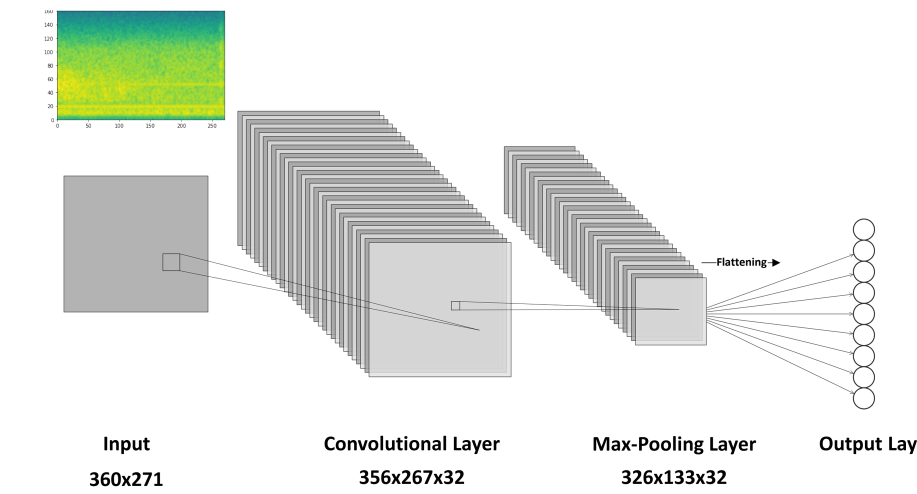


Example of the echo recordings obtained: (a) full recording including the direct pass-through of the transmit signal (3 ms linear chirp from 100kHz to 20kHz, with a Hanning envelope) trailed by the clutter echoes. In subfigure (b) clutter echoes (approximately 4ms duration) segmented from the recording. The clutter-echo segment was used as input to the deep-learing classifier for the pinna shape conformation.

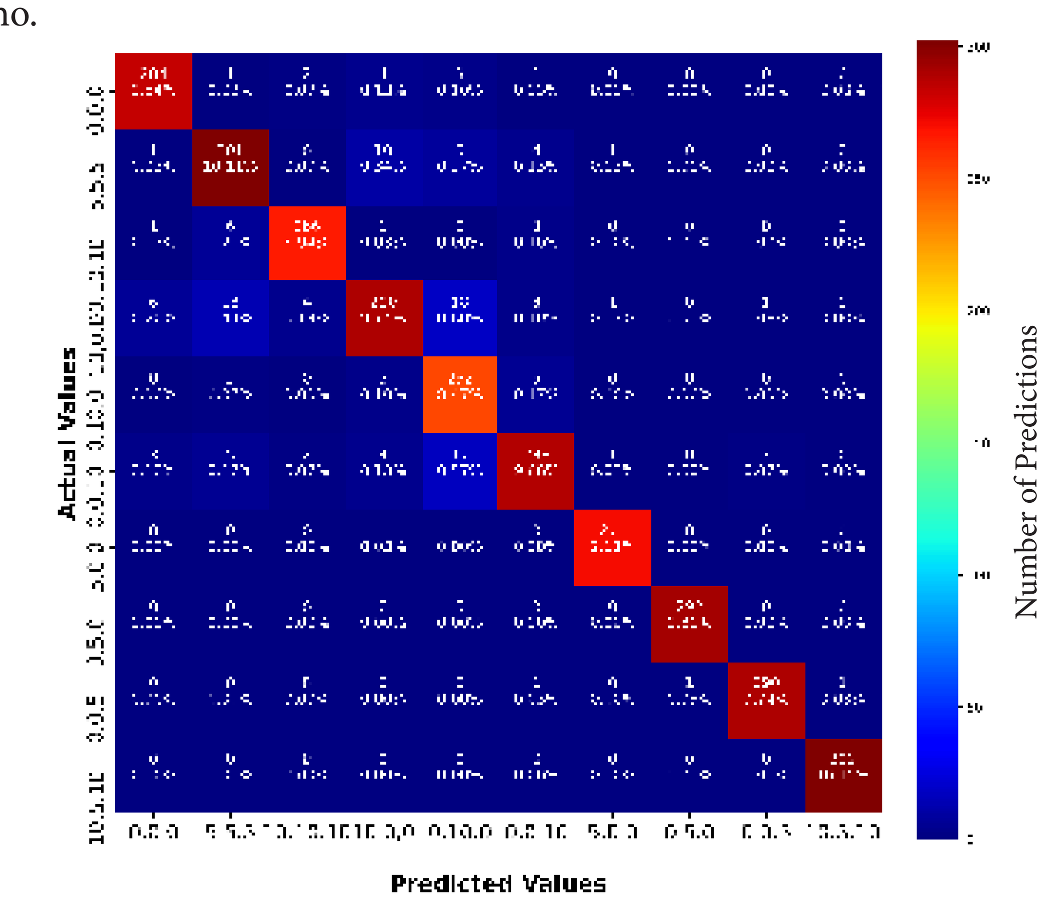


Correlation structure of the echo data collected: (a) clutter echo samples collected without operation of the fans used to agitate the foliage, leading to a strong correlation in the dataset with an average correlation coefficient of 0.79. (b) fans activated to agitate the foliage between each echo recording, leading to a significant decrease in correlation to an average correlation coefficient of 0.22. This shows that running the fans and agitating the foliage successfully decorrelates any two consecutive echoes, ensuring that the inputs to the convolutional neural network have little structural similarity.

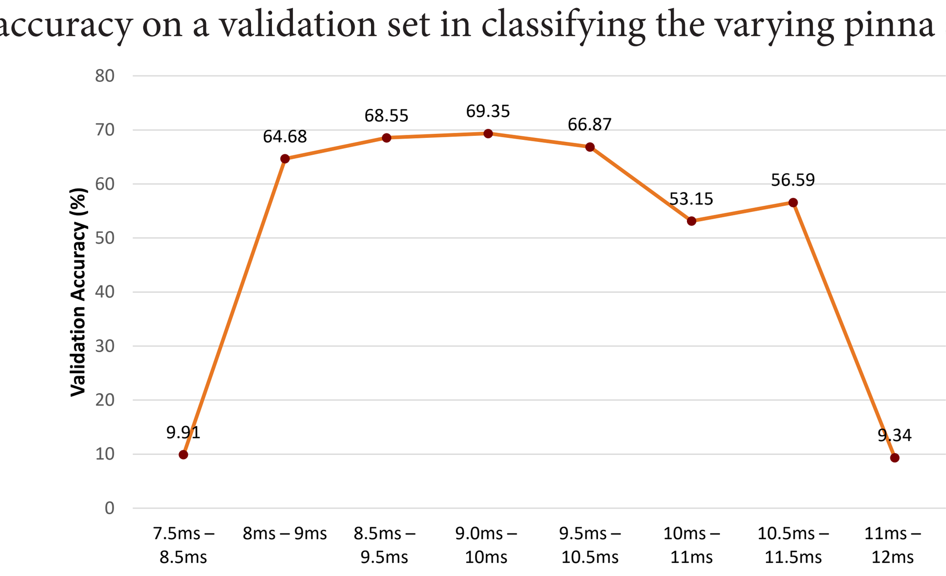
Results & Discussion



The deep learning network architecture (convolutional neural network) used to identify the pinna shape given the spectrograms a single clutter echo.



Using the full 4 ms clutter echo, the confusion matrix shows a close to 90% accuracy on a validation set in classifying the varying pinna shapes.



Effect of windowing the clutter echo, a 1 ms sliding window with 0.5 ms overlap was applied to the 4 ms clutter-echo segment. The effect of the time window location on the validation accuracy is shown.

Conclusion

The results show that despite the random nature of clutter echoes, even a small pinna deformation can have a consistent and predictable effect on the received clutter echo. The consistent nature of these effects is a necessary condition for potential applications of the pinna dynamics to sensing tasks involving clutter echoes.

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