# CHAT Mask: Underwater Head-worn Display for Visualizing Wild Dolphin Communications Report

## CS4605/7470-A Mobile and Ubiquitous Computing

LEONID ALEXEYEV, ETHAN LIANG, CYNTHIA PENG, and JASON ROM, Georgia Institute of Technology, USA

We prototyped the CHAT Mask, a lightweight head-worn display system to visualize communications from wild dolphins. The system is designed to integrate into the scuba diving kits of researchers from the Wild Dolphin Project conducting in-water sessions with wild Atlantic spotted dolphins in the Bahamas. The CHAT Mask records underwater audio and presents users with near real-time waterfall spectrograms, allowing researchers to manually classify dolphin communications and guide interactions accordingly. The system uses the SCUBAPRO Galileo HUD Hands-Free Computer, a commercial underwater display, as a hardware starting point for its housing, user input, and optics.

Our prototype of the CHAT Mask records audio, generates near real-time waterfall spectrograms, and presents them graphically to users; it is ready for final assembly and packaging into the Galileo, after which it may be tested in the field. The designed system features an internally mounted microphone, a micro controller, a display with associated optics, a rotary encoder and switch for user input, and a battery with associated charging circuit using the Galileo's existing USB charging interface.

CCS Concepts: • **Human-centered computing → Mixed / augmented reality**.

Additional Key Words and Phrases: head-worn display, dive computer, underwater, spectrogram, wild dolphin, scuba dive, augmented reality

## 1 Introduction

Herzing et al. [2024] of the Wild Dolphin Project have swum alongside wild Atlantic spotted dolphins in the Bahamas for several years to understand their ability to engage in two-way communications. To this end, the Cetacean Hearing Augmentation Telemetry (CHAT) wearable computer was developed to play and recognize computer-generated sounds (CGS) that were distinct from (yet resembling) dolphin whistles, thereby facilitating communication between researchers and dolphins. The CHAT system consists of two input hydrophones and one output speaker; initial testing showed that it could achieve a 98 percent recall rate on detecting CGS emitted by a second device, even in a noisy environment [Kohlsdorf et al. 2013].

In practice, however, the CHAT system almost never detected imitations of CGS by dolphins, despite on-site validation by researchers that the devices could achieve 95 percent recall on CGS generated by another device. As Herzing et al. [2024] note, this is because none of the dolphins' vocal responses to CGS actually completely replicated the CGS: responses were transposed in frequency, overlapping with CGS playback, or even took the form of click trains whose frequency modulations matched the contour of the CGS of interest. As a result, researchers were unable to identify vocal mimics until they manually inspected spectrograms post-session, hindering their ability to engage in two-way communication with dolphins. A visual feedback system, the CHAT Mask, is thus desired to facilitate this visualization and manual classification in real time.

The Wild Dolphin Project has used different methods in the past to capture audio. The CHAT system uses two large SQ26-series hydrophones and a USB ADC chip from a commercial product [Kohlsdorf et al. 2013]. The team has also used Hydromoth devices for audio recording [Wild Dolphin Project 2024].

### 1.1 Challenges

*1.1.1 Head-worn Display.* The CHAT Mask is a head-worn display design problem but in the underwater space, which could affect existing understandings of human interactions with head-worn systems.

*1.1.2 Environment.* The Wild Dolphin Project conducts research off the coast of the Bahamas, and this environment challenges wearable devices due to the risk of damage from water, saline content, and UV rays. The original CHAT system features a custom aluminum case waterproofed with an O-Ring secured by 14 bolts [Kohlsdorf et al. 2013]. Our proposed CHAT Mask will occupy an even more compact space than the original CHAT system, requiring even more precise waterproofing systems. Another risk comes from the salinity of the Atlantic sea in which the dolphin research takes place. Salt can corrode metals and degrade electronic connections, restricting necessary current flowing in computers and damaging hardware [Talukder et al. 2025]. Since the audio sensors and electronic displays in the mask are going to be in a highly saline environment, choosing proper materials that resist corrosion and designs that limit exposure is important. One final hazard to wearable computers in this environment is UV rays. Polymers used in the mask and wearable computers can degrade due to UV photo-degradation, reducing strength and making them susceptible to cracking [Redjala et al. 2020]. Since the electronics implemented will be protected by these polymers, ensuring they do not crack due to constant exposure to the sun's rays and let water into the system is critical. The heavy sunlight in the Bahamas also presents an issue with display brightness and contrast. The display should be visible to users even in the bright and sunny environments of the Bahamas.

*1.1.3 Real-Time Visualization.* The CHAT Mask must be performant enough to process audio, generate a spectrogram, and display in near-real-time. Pre-processing using filters is required to eliminate noise from the environment and isolate desired sounds to ensure a clean display. The FFT for the display must be calculated in a timely manner for near real-time display. In addition, researchers may want to be able to look back temporarily at previous signals while underwater. This requires classification in our system in order to detect call-response pairs and save them for immediate review and display by the diver. Having a device that can perform all of

Authors' Contact Information: Leonid Alexeyev, lalexeyev3@gatech.edu; Ethan Liang, eliang@gatech.edu; Cynthia Peng, cpeng80@gatech.edu; Jason Rom, jrom6@gatech.edu, Georgia Institute of Technology, Atlanta, Georgia, USA.

these tasks while being small enough to comfortably be on a divers mask while in the ocean will be a main challenge.

*1.1.4 Compact Visualization of Spectrograms.* Head-worn displays are subject to restrictive size and resolution requirements, so constructing a useful spectrogram display is a challenge for the CHAT Mask. The spectrogram will have to be optimized to show as much useful data in both the time and frequency dimensions as possible, while still being interpretable to the human researcher. In addition, the environment of diving underwater in the Atlantic ocean can be strenuous, so our display should be as easy to understand as possible. Experiments will have to be conducted to determine what volume of information presentation at once is useful yet interpretable to the Wild Dolphin Project's researchers.

## 2 Background / Relevant Work

### 2.1 Dolphin Vocalizations

In early dolphin vocalization research, researchers used techniques including attachment of tags and loggers to dolphins [Tyack 1991], [Nowacek et al. 1998]. The invasive nature of these techniques had potential to alter natural behavior, leading researchers to use bubble streams created during whistles to identify vocalizing dolphins [McCowan and Reiss 1995]. Although non-invasive, only a small fraction of whistles actually produced bubbles.

Researchers have also long been interested in localization of dolphin vocalizations, and techniques have been developed using combined video and audio recordings [Dudzinski et al. 1995], which yielded limited localization resolution, or multichannel hydrophone arrays [Au and Herzing 2003], [Schotten et al. 2004] that localized click emitters rather than whistles or more complex vocalizations. The BaBeL system is a five-hydrophone array 360 degree HD audio-video device that combines video data with hydrophone time stamps, to improve localization in large groups of dolphins [López-Marulanda et al. 2017]. The system's accuracy showed the importance of using visual context in conjunction with audio analysis, but mainly showed this performance after post-processing, which limited its effectiveness in real-time applications.

The problem of identifying specific vocalizations (such as classifying unique signature whistles) is more difficult. Studies have shown that humans outperform statistical methods at identifying signature whistles [Janik 1999]. Other, more modern, works classify whistles into grouped types [Kriesell et al. 2014] rather than identifying individual whistles with temporal or frequency shifts.

Our proposed CHAT Mask focuses on real-time human judgment, relying on human knowledge to take the accuracy improvements found in post-processing and apply them directly to the spectrograms underwater. It does this by allowing researchers to perceive dolphin vocalizations in real time by presenting a spectrogram.

### 2.2 Head-worn Displays

Gallagher [1999] showed that head-worn displays could be applied with efficacy in the underwater environment to expose sensor data to divers. Major lessons from their work concentrate on human factors; users emphasized the ability to easily detach the head-worn system, to use their dominant eye for tasks requiring focus on the monocular display for extended durations, and to have the ability to adjust the position of the display.

The positioning of a contentful head-worn display is also well researched; for example, Chua et al. [2016] find that content positioned at the top and peripheral positions felt the most unobtrusive, while middle- and bottom-center positioning is preferred when high attention on the displayed content is required for the real-world visual task. Additional testing with the prototype will be necessary to determine if these findings transfer to the underwater environment.

## 3 Device Development

### 3.1 Original Aims & Objectives

Our original aims were to deliver the CHAT Mask, an underwater head-worn display with near-real-time waterfall spectrograms of dolphin vocalizations. We specified that the CHAT Mask would be a lightweight and ergonomic addition to researchers' dive kits to facilitating quick turnaround into and out of the water. We identified the following functionalities of the system:

- Real-time spectrogram display
- Rewind functionality
- Export functionality (e.g., via SD)

### 3.2 Hardware

Before we could begin developing the device, hardware elements needed to be selected that would be suitable for the task at hand. We determined that using the Galileo HUD as a starting point would be a fantastic choice, due to it having a small screen integrated in the device that could be used to display the spectrograms.

Initially, we considered using a hydrophone, specifically the SQ26-08, which would require external mounting with a wire running into the Galileo HUD. However, in order to reduce the complexity with waterproofing and reduce loose wires, we decided to look at the Audiomoth unit, which gave us the idea of using a regular microphone pressed against the inner plastic of the casing in order to pick up sounds. We decided to take a small simple microphone and do this manually inside the Galileo HUD, eliminating the need for wires running into the casing. In general, dolphin whistles occupy frequencies up to around 25 kHz, meaning that the microphone must capture at least 48 kHz sample rate, but ideally support 96 kHz. For our prototype, we selected the Analog NEMS Microphone, as it supported capturing most dolphin whistles for our FFT (typically in range 5-25 kHz). This microphone has a bandwidth of around 80 kHz, meaning we can capture a good range of whistles, and its small size and analog output allowed for easy integration with the interface.

When selecting a compute module, we knew that we needed something with real-time audio capability, compact size, and relatively high processing power. We went with the Teensy 4.0, as its high clock speed and open source Audio Management libraries allowed us to perform real-time FFT computation, windowing, log-scaling, and filtering with no dropped frames and visual discrepancies to the users. The Teensy is especially efficient at accelerating multiplicative and vectorized math, which was integral as part of our spectrogram pipeline. Additionally, its small size was ideal for fitting inside the Galileo HUD, ensuring quick and efficient computation with a modest power consumption allowing for longer dives with the spectrogram device active.

For the display, we selected the TinyScreen OLED module (96x64 pixels), as it had roughly the same size and resolution as the display which had come in the Galileo HUD. In doing so, we knew that it would fit well in the previous display location, and work well with the built in optics that project the screen towards the users vision on the mask. The OLED RGB display ensured that we could provide a high contrast and high brightness picture, which is especially important in bright environments such as the Bahamas. Additionally, the TinyScreen uses a high speed SPI interface, which allows for rapid column updates for the scrolling display broadcasted from the Teensy. With this high performance, the TinyScreen manages to keep a relatively low power draw, which is integral as we have a limited sized battery pack contained within the Galileo. In order to harness this battery power, we opted for a simple (and very small) Adafruit battery pack, which integrates well with the one already included in the HUD display.

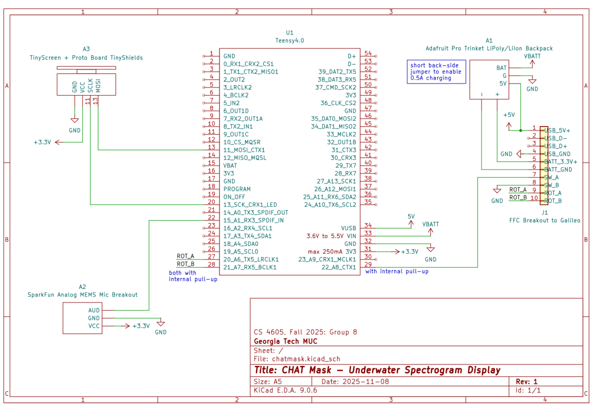


Fig. 1. Wiring diagram for CHAT Mask

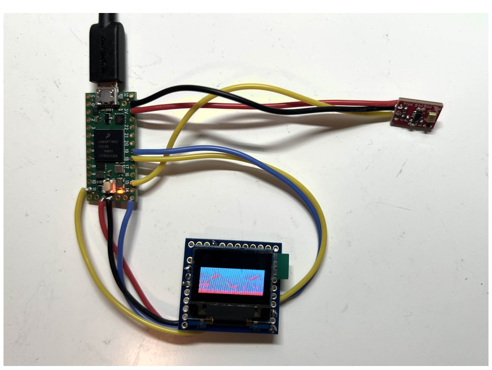

Fig. 2. Fully wired device displaying an Atlantic Spotted Dolphin whistle

## 3.3 Software

The Teensy 4.0 was used to create a software pipeline to implement the real-time spectrogram display. We developed modularized code for each section of the audio processing pipeline to ensure ease of implementation and readability of code.

*3.3.1 Pre-processing.* Before we can use the audio data from the microphone, the data must be preprocessed to ensure clean display of spectrograms. High contrast displays would be necessary With the bright, sunny environment of the Bahamas where the CHAT Mask would be used and proper noise removal would improve the contrast of the spectrograms. Pre-processing methods were tested within a Python script before developing the final Arduino code in C++.

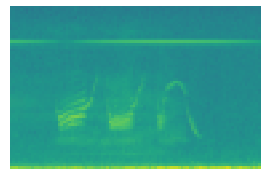

Fig. 3. Raw 3 second 1024-point spectrogram of an Atlantic Spotted Dolphin whistle

In the processing pipeline, blocks of audio data taken from the Analog NEMS microphone normalized and passed through a high pass filter to remove noise. We set the high pass filter to filter out any noise below 50Hz, which mainly consisted of ocean noise that the researchers had no interest in.

*3.3.2 FFT Transformation.* The cleaned data was then converted into an FFT and added to a ring buffer for display. For the FFT calculation, we opted to use the built-in 256-point FFT. Although a 1024-point FFT calculation was also available for usage and would result in a high resolution image, we opted for the 256-point calculation due to the quicker run time, which was necessary for a real time display. FFT cost grows as $O(N \log_2 N)$, meaning the 256-point calculation is roughly 5 times faster.

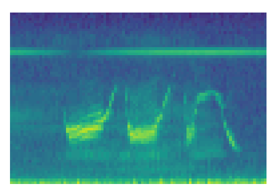

Fig. 4. Processed 3 second 256-point spectrogram of an Atlantic Spotted Dolphin whistle

*3.3.3 Ring Buffer Display.* Once each FFT block was calculated, the display would be updated with the new data. The FFT would first be converted to colors for the display on the TinyScreen. Due to the small resolution of the TinyScreen display of 96 by 64 pixels, the FFT needed to be down-sampled and two frequency bins were averaged for each pixel in the display for most accurate visuals. Additionally, we employed log scaling in order to enhance contrast between quiet

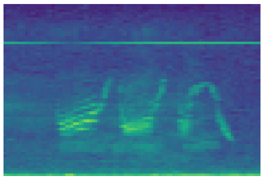

Fig. 5. Processed 3 second 1024-point spectrogram of an Atlantic Spotted Dolphin whistle

and loud components of the signal, making faint dolphin whistles more visible on the low-resolution display.The color column was then stored within a ring buffer for display. We decided to choose a ring buffer for the display so that the FFT and color is only calculated for each incoming block of data and the rest of the data is shifted 1 pixel down, which reduces redundant computations in our system. Since the device will be used in a real time setting while users are diving, the responsiveness of the device is of the utmost importance. By reducing the number of expensive FFT calculations with each screen refresh, we are able to improve the speed and responsiveness of the device.

*3.3.4 Knob Input.* While taking apart the Galileo HUD, we were able to reverse engineer the pinout and identify which pins correspond to the knob input. We did some light testing with the knob, finding that it acts as a potentiometer and a button, and have plans to implement manual scrolling and shut down functionality.

## 4 Results

### 4.1 Overall Device

Throughout the semester, we were able to create a device to take in raw audio data from the samples and convert it to a spectrogram display on the TinyScreen. We have employed an efficient and modular software pipeline, which splits the process into three distinct stages: audio input, processing, and display. Our components are prepared for insertion into the Galileo HUD, and all components are soldered together with consistent prototype behavior.

### 4.2 Spectrogram Display

In the final device, the TinyScreen display displays a 96 x 64 resolution spectrogram approximately 1.75 seconds of audio data, due to overhead from SPI transfer and frame buffer shift. The whistles are clearly displayed, although there is some noise present in the low frequency of the spectrograms generated. The colors chosen for the sound waves and background have high contrast, ensuring that they are visible even in difficult visibility conditions.

### 4.3 Physical Design

Although the final waterproof casing has not been created yet, we have created CAD models of the device. This was designed with the limited space of the Galileo HUD as the main constraint. Additionally, we have reverse engineered the pinouts in the Galileo HUD, and have found out how to use the knob for potentiometer and button input into our system.

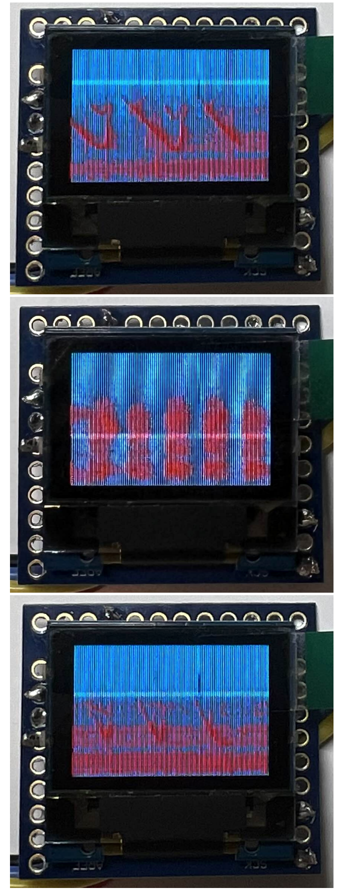

Fig. 6. A display of a variety of Atlantic Spotted Dolphin whistles using the wired prototype

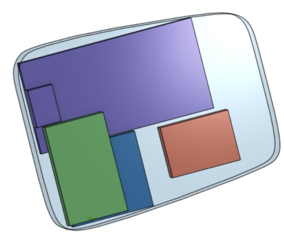

Fig. 7. Planned CAD Model of the device

With this design, we can ensure a lightweight, waterproof design suited for dives in the Bahamas.

## 5 Reflection

### 5.1 Challenges

When we first began the project, we were quite optimistic in our project timeline and scheduling for developing the device. However we came across a couple issues that limited what we could achieve in the project. One main challenge came from delays in receiving the Galileo HUD to work with. These delays with obtaining the Galileo meant that the exact interior dimensions were unknown for an extended period of time, which limited planning what hardware could be used. This was because of the critical challenge that space is in integrating the spectrogram into the small interior space in the Galileo computer. If not fitted properly, connecting the Teensy, display, and microphone together in a small space can cause unwanted shorts between the pins. Packing the hardware too tightly can also cause damage to connections and components and internal pressure that can push on the O ring and make the device not waterproof. Without the actual Galileo, understanding how the new hardware could be placed was extremely difficult. Once the Galileo was received, internal free space was measured ($48 \times 36 \times 5$ mm$^3$) to help select hardware. Having a physical Galileo made us understand a clear line of sight had to be maintained from the screen to the viewing area, adding additional limits to the available space that we would not have found otherwise. In the time available after obtaining the Galileo, 3D printing a base to support the selected hardware inside while accounting for space considerations was not achievable. The needed dimensional accuracy that would be required for the base in a precise fit meant that multiple iterations of the base would have to be made. In addition the delay in selecting the hardware due to the late arrival of the Galileo made the wiring of the components uncertain, which limited the work that could be done on the 3D printed support. Due to this, the spectrogram generator could not be integrated into the Galileo HUD. The seek function also was not achieved in the scope of this project as without the Galileo, understanding the knob which would control the function precisely was not possible. Even though we were unable to reach all of the goals that we had originally hoped and reduced the scope of the project, these missed tasks can be worked on in the future using the project base that we have created.

### 5.2 Achievements

Even though we encountered logistical challenges and could not complete some objectives, other goals were completed successfully. We created a program to create a live spectrogram display that can be placed into the Galileo with live sound data. This spectrogram, when integrated in the Galileo, will allow divers to look at sound data consistently while performing other tasks which was a major motivating factor for this project. Another achievement was soldering working connections between the Teensy, display, and microphone. This proved the spectrogram program's function and also helped create a wiring diagram between all the components that would be in the Galileo. This diagram will be useful for future work when implementing the prototype in the HUD. Another achievement was the creation of CAD files for the interior space of the Galileo. These files can be used as an accurate model for available space in implementation. This work that was done on a rearranged schedule will be very helpful for future teams and work, showing the importance of shifting plans when unforeseen challenges occur.

## 6 Next Steps

With the device hardware setup and base software created, the project can be easily expanded to add original goals of the seek functionality to the system using the potentiometer knob of the Galileo HUD and export functionality. Along with the seek functionality, a notable features algorithm to distinguish sounds of interest within the data could also be implemented for ease of usage for the user. Instead of having to scroll through long periods of ocean noise using the seek functionality, users would be able to review sections of data flagged by the algorithm instead, increasing ease of usage. However, the sensitivity of the algorithm would be of the utmost importance as users could miss data if it is not flagged as an important event by the algorithm. Future development could also consider implementing a shutdown function. This would allow users to shut off computationally expensive features such as the real time spectrogram display to save the battery of the device. Since the usage of the device is limited by its battery, the ability to shut down the device during unnecessary times, such as above water would subsequently allow for longer dives and usage of the device.

In order for us to achieve our initial project goal, we will need to add the battery pack implementation and fit everything within the casing of the Galileo HUD. Further testing of the device would be valuable, especially in the Bahamas climate to ensure high visibility of the display.

Additionally, we hope to upgrade the microphone, and write custom FFT and processing code in order to obtain a higher sampling rate and account for higher pitched whistles and harmonics. The latter would be required, as the open source AudioManager library we use from Teensy is optimized for a 44 kHz sampling rate.

## References

Whitlow W. L. Au and Denise L. Herzing. 2003. Echolocation signals of wild Atlantic spotted dolphin (Stenella frontalis). *The Journal of the Acoustical Society of America* 113, 1 (2003), 598–604. doi:10.1121/1.1518980

Soon Hau Chua, Simon T. Perrault, Denys J. C. Matthies, and Shengdong Zhao. 2016. Positioning Glass: Investigating Display Positions of Monocular Optical See-Through Head-Mounted Display. In *Proceedings of the Fourth International Symposium of Chinese CHI* (San Jose, USA) *(Chinese CHI '16)*. Association for Computing Machinery, New York, NY, USA, Article 1, 6 pages. doi:10.1145/2948708.2948713

Kathleen A. Dudzinski, Christopher W. Clark, and Bernd Würsig. 1995. A mobile video/acoustic system for simultaneous underwater recording of dolphin interactions. *Aquatic Mammals* 21, 3 (1995), 187–194.

D.G. Gallagher. 1999. Development of miniature, head-mounted, virtual image displays for navy divers. In *Oceans '99. MTS/IEEE. Riding the Crest into the 21st Century. Conference and Exhibition. Conference Proceedings (IEEE Cat. No.99CH37008)*, Vol. 3. 1098–1104 vol.3. doi:10.1109/OCEANS.1999.800143

Denise Herzing, Adam Pack, Fabienne Delfour, Thad Starner, Celeste Mason, Scott Gilliland, Charles Ramey, and Daniel Kohlsdorf. 2024. Imitation of computer-generated sounds by Wild Atlantic spotted dolphins (Stenella frontalis). *Animal Behavior and Cognition* 11, 2 (May 2024), 136–166. doi:10.26451/abc.11.02.02.2024

Vincent M. Janik. 1999. Pitfalls in the categorization of behaviour: a comparison of dolphin whistle classification methods. *Animal Behaviour* 57, 1 (1999), 133–143. doi:10.1006/anbe.1998.0923

Daniel Kohlsdorf, Scott Gilliland, Peter Presti, Thad Starner, and Denise Herzing. 2013. An underwater wearable computer for two way human-dolphin communication experimentation. In *Proceedings of the 2013 International Symposium on Wearable Computers* (Zurich, Switzerland) *(ISWC '13)*. Association for Computing Machinery, New York, NY, USA, 147–148. doi:10.1145/2493988.2494346

Hannah Joy Kriesell, Simon Harvey Elwen, Aurora Nastasi, and Tess Gridley. 2014. Identification and characteristics of signature whistles in wild bottlenose dolphins (Tursiops truncatus) From Namibia. *PLoS ONE* 9, 9 (2014). doi:10.1371/journal.pone.0106317 Cited by: 63; All Open Access, Gold Open Access, Green Open Access.

Juliana López-Marulanda, Olivier Adam, Torea Blanchard, Marie Vallée, Dorian Cazau, and Fabienne Delfour. 2017. First Results of an Underwater 360° HD Audio-Video Device for Etho-Acoustical Studies on Bottlenose Dolphins (Tursiops truncatus). *Aquatic Mammals* 43, 2 (2017), 162–176. doi:10.1578/AM.43.2.2017.162

Brenda McCowan and Diana Reiss. 1995. Maternal aggressive contact vocalizations in captive bottlenose dolphins (Tursiops truncatus): Wide-band, low-frequency signals during mother/aunt-infant interactions. *Zoo Biology* 14, 4 (1995), 293–309.

doi:10.1002/zoo.14301404022
Daniel P. Nowacek, Peter L. Tyack, Randall S. Wells, and Mark P. Johnson. 1998. An onboard acoustic data logger to record biosonar of free-ranging bottlenose dolphins. *The Journal of the Acoustical Society of America* 103, 5 (1998), 2908.
S. Redjala, N. Aït Hocine, R. Ferhoum, M. Gratton, N. Poirot, and S. Azem. 2020. UV aging effects on polycarbonate properties. *Journal of Failure Analysis and Prevention* 20, 6 (Sep 2020), 1907–1916. doi:10.1007/s11668-020-01002-9
Marcel Schotten, Whitlow W. L. Au, Marc O. Lammers, and R. Aubauer. 2004. Echolocation recordings and localization of wild spinner dolphins (Stenella longirostris) and pantropical spotted dolphins (S. attenuata) using a four-hydrophone array. In *Echolocation in Bats and Dolphins*, J. A. Thomas, C. F. Moss, and M. Vater (Eds.). University of Chicago Press, Chicago, IL, 393–399.
Amit Talukder, Charles Freeman, Caroline Kobia, and Reuben F. V. Burch. 2025. Assessing Corrosion Effects on the Electrical Performance of Wearable Photovoltaic Cells: A Comparative Analysis of Current Consistency and Resistance. *Materials* 18, 2 (2025). doi:10.3390/ma18020267
Peter L. Tyack. 1991. Use of a telemetry device to identify which dolphin produces a sound. In *Dolphin Societies: Discoveries and Puzzles*, K. Pryor and K. S. Norris (Eds.). University of California Press, Berkeley, CA, 319–344.
Wild Dolphin Project. 2024. The Hydromoth — a Passive Acoustic Monitoring Device. https://www.wilddolphinproject.org/the-hydromoth-a-passive-acoustic-monitoring-device/. Accessed: 2025-12-02.

## 7 Appendix

Github: https://github.com/lalexeyev/chat-mask

We have included the Github, which has all necessary resources to continue the project within Github. Both software and hardware technical documents are included.