Dual-Use Wideband Microphone Array System

Phonons & Photons

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Background

As humanity ventures into space, NASA loses the ability to monitor vessel devices remotely. This generates a need for a portable, passive system that can be deployed in various environments and is able to detect and locate equipment malfunctions, pressure leaks, and other problematic issues.

Purpose

The goal of this project is to design a device capable of functioning as a medium for voice transmission as well as be able to detect and locate ultrasonic anomalies. Upon detection, the system will alert crew members through audible and visual cues. Combining these two functions increases safety and can save valuable space onboard different vessels and habitats.

What is an Ultrasonic Anomaly?

A frequency signal that cannot be heard by the human ear and is a sign of malfunctioning equipment. When equipment starts to fail, or a valve begins to leak, it can be detected before it turns into a serious problem. This potential problem is seen through the ultrasonic frequency emission of these failures. Detecting this problem early can help keep crew members safe before a small problem turns into a big problem.

Current Installment

Currently, NASA institutes a handheld sniffer, which requires a user to scan walls with a portable device. With a narrow detection zone and the constant need for the crew's time, detecting anomalies can be laborious and time consuming. In 2020, NASA spent multiple weekends in one segment of the ISS trying to pinpoint a leak using this method.

Fig. 1: Current method used by NASA today

Design Requirements and Features

- Array of MEMS microphones to create a proof-of-concept detection system.
- Provide and transmit hands free voice communication to users.
- Ultrasonic anomaly detection that alerts users through a 1 Hz tone that is silenced when acknowledged by user.
- Anomaly detection uses a sonification to alert crew to signal's intensity.
- An interactive screen will have acknowledgement controls and signal the presence and location of anomaly detection.

Future Design Plans

- Switch analog devices to a fully digital implementation where filtering and processing can be done by the MCU.
- Incorporate 5 additional MEMS microphones into the vocal array to provide beam forming functionality.
- Enhanced localization feature through more complete dataset creation.
- Include vocal anomaly alerts by using recorded speech.

Acknowledgments

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NASA & The Texas Space Grant Consortium
Team Sonus & Team Electronauts

References and Questions

Video pitch can be found by scanning:

For more information, please contact Seth Mills at ani24@txstate.edu

References can be found by scanning:

Fig. 2: The size reduction between the first conical horn (left) and the final horn design (right).

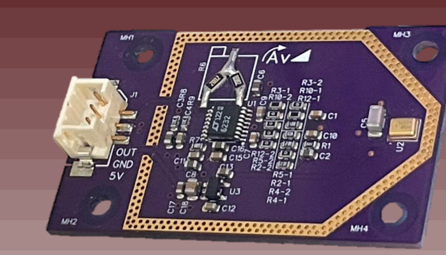

Fig. 3: Analog chain PCB responsible for filtering and amplifying anomaly signal.

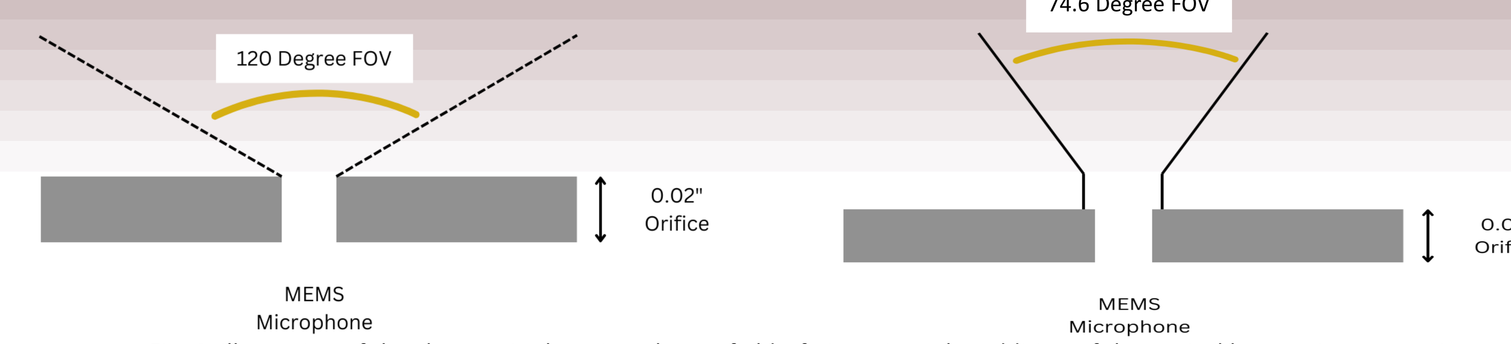

Fig. 4: Illustration of the changes in the microphones field-of-view given the addition of the conical horn to increase gain.

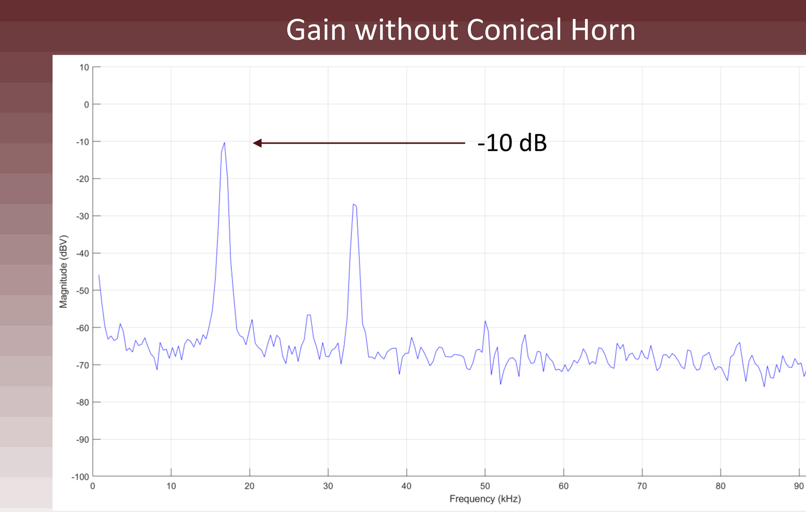

Fig. 9: Ultrasonic detection magnitude without conical horn.

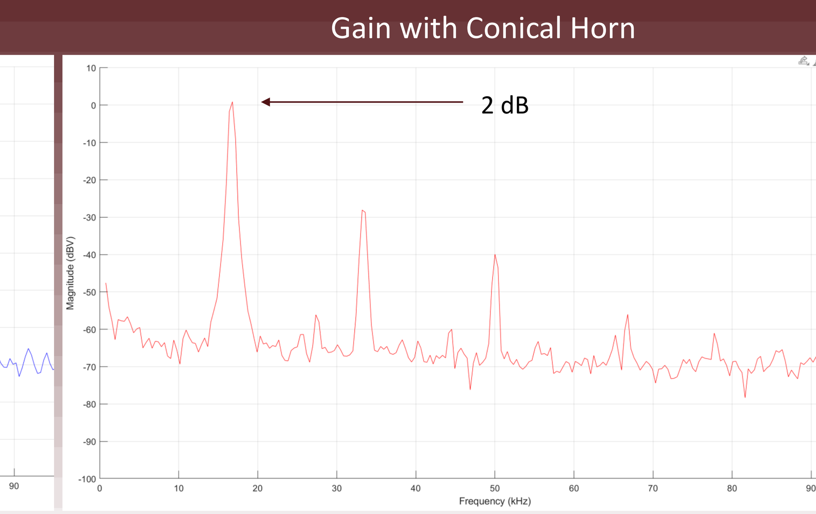

Fig. 10: Ultrasonic detection magnitude with conical horn.

Table 1: Ultrasonic detection range with the conical horn.

Range	Detection	FFT Magnitude
1m	Yes	-26 dB
2m	Yes	-33 dB
3m	Yes	-39 dB
4m	Yes	-46 dB

Ultrasonic Detection Design

- Addition of conical horn to increase detection range – sacrificed field of view.
- Analog chain with low/high pass filters to reduce noise and boost signal.
- Array design to detect 360 degrees with 12 distinct regions.
- Optimized conical horn to take up less space while maintaining sufficient range.
- Vented design allows for proper airflow to ensure devices do not overheat.

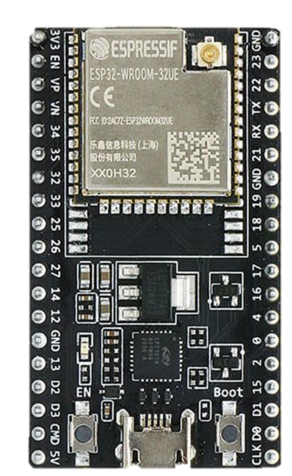

Fig. 5: ESP32 responsible for audio VoIP.

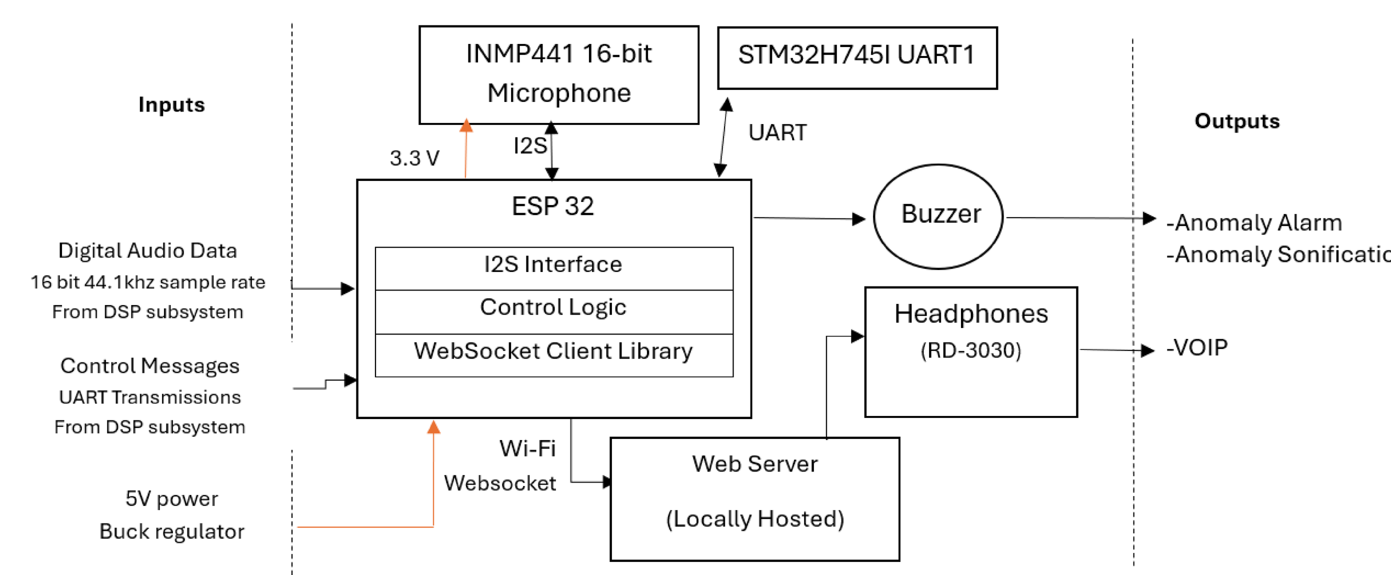

Fig. 6: Block diagram depicting the integration of the ESP32 into the microphone array system.

ANOMALY SONIFICATION

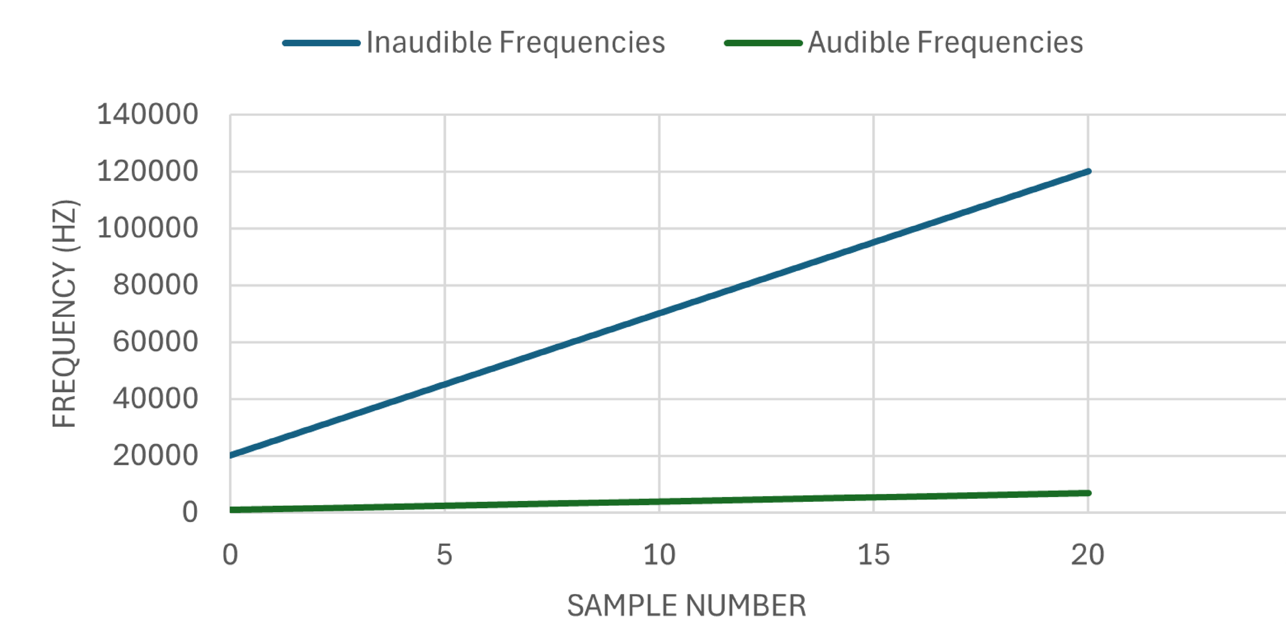

Fig. 11: Remapping the inaudible ultrasonic frequencies into the audible range (200-6000 Hz).

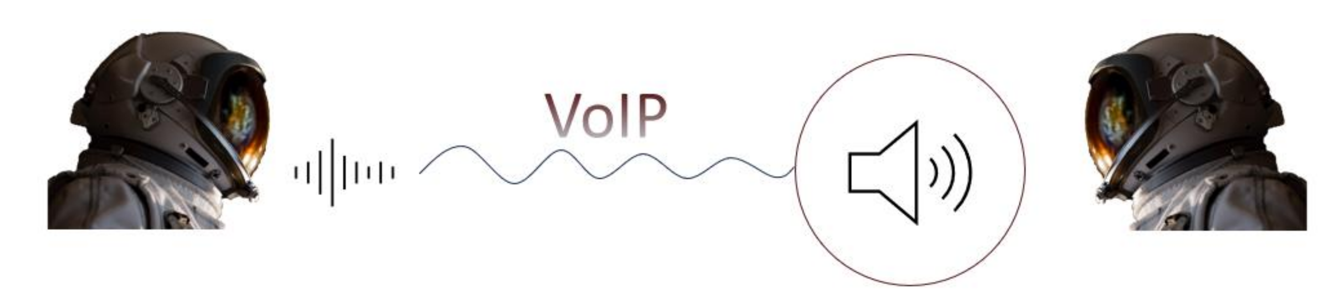

Fig. 12: Visualization of VoIP functionality

Audio System Design

- Integrated ESP32 to handle audio communications as a follower to the STM32.
- Remaps the ultrasonic frequencies to the audible range giving the option to hear the signal.
- ESP32 WIFI capabilities used to connect to remote server allowing VoIP communication.
- Any computer/device can be connected to the remote server giving access across the vessel.
- Volume control and system status alerts able to be adjusted/viewed on remote server.

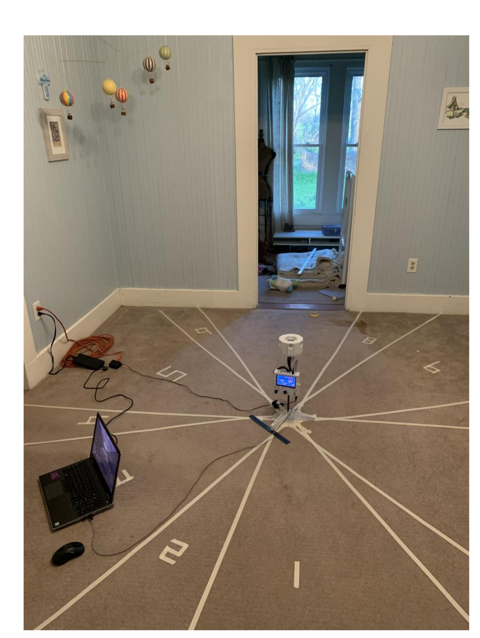

Fig. 7: Visual of how the localization dataset was built.

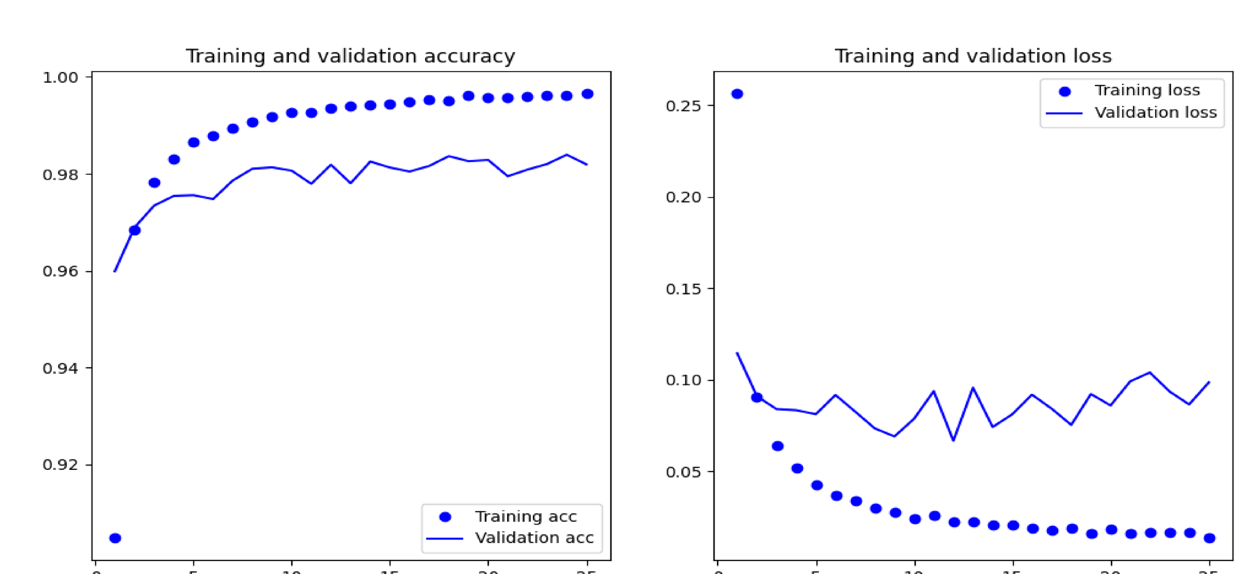

Fig. 8: Accuracy and loss curves for ANN trained on dataset from Fig. 7.

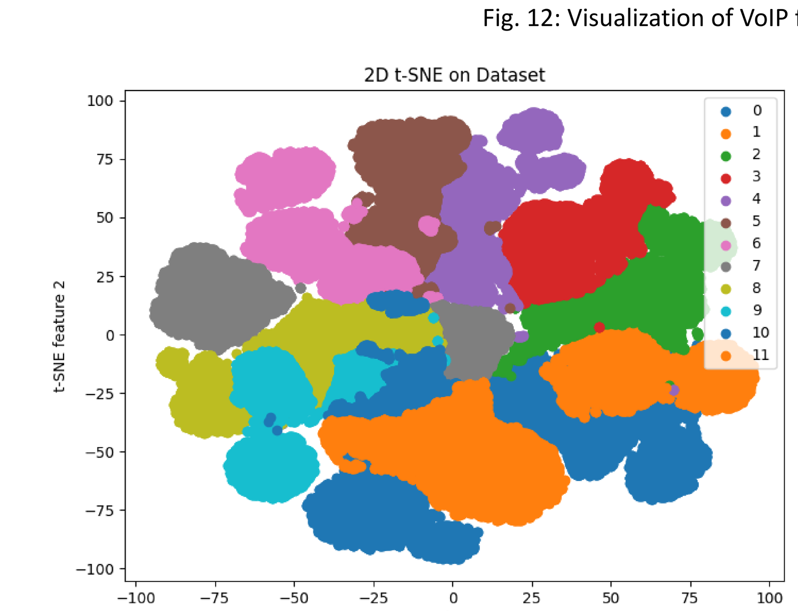

Fig. 13: Dataset shows well-defined separation between classes, local and global clustering.

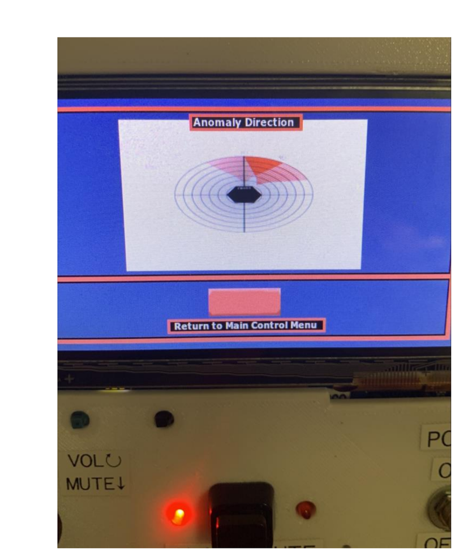

Fig. 14: GUI response to an anomaly in a specific region.

Digital Signal Processing

- Interactive interface to mute voice, acknowledge ultrasonic detection & view anomaly origins.
- Localization function processed through machine learning algorithm to pinpoint anomaly occurrence.
- FFT of ultrasonic anomaly to provide frequency and magnitude values used in signal sonification.
- Audible/visual cues to alert to the presence of an anomaly, localize feature shows the distinct region.
- Prioritizes anomaly detection over audio transmission – automatically mutes audio when anomaly detected.

Conclusions

- Passive system designed to detect both voice and ultrasonic signals.
- Voice transmitted over VoIP to provide communication anywhere in the habitat.
- Anomaly detection feature shows the localization of the ultrasonic signal and details intensity and frequency through audible sonification.
- Improved range and field-of-view over current NASA solution.