E1.01 – TSGC NASA

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Revision History Table		Template Date 1/29/2020
Version	Summary of Changes	Date
0.1	Section Owners assigned; draft Introduction added	09/15/21
0.2	Template info removed; first draft of all sections completed	09/26/21
0.3	All sections updated during first team review	09/28/21
0.4	All sections updated during second team review	09/29/21
0.4	Version submitted for feedback	09/30/21
0.5	All sections updated during third team review	10/03/21
0.6	Removed all comments, made minor edits to sections for coherency, and added NASA logo to front page	10/04/21
1.0	Final version sent for approval signatures	10/04/21

Contents

1. EXECUTIVE SUMMARY

The Executive Summary was written by Olivia Salazar- Mendez.

Team Sonus will be building a proof-of-concept prototype dual-use omnidirectional wideband micro-electromechanical system (MEMS) microphone array that will detect human vocal range (200Hz - 6kHz), relay the detected vocal message over a speaker, and identify ultrasonic frequencies (>20kHz) that indicate anomalies such as air leaks. If an ultrasonic sound is detected, the product prioritizes it over a voice and will alert personnel with an audio alarm that can be disabled manually by the user. A visual alarm will also be triggered by the detection of the ultrasonic frequency. A stretch goal is to localize where the leak is with a 2D vector display indicating the direction of the ultrasonic frequency.

This product is important because it can serve as early automated leak detection for pressurized vessels of various types, such as spacecraft, airplanes, or certain industrial equipment. With the continued exploration and study of space, NASA needs the product to ensure equipment is operating appropriately and that there is no immediate risk to the mission or the crew.

Currently, NASA is utilizing its Robotic External Leak Locator (RELL) which allows them to detect the directions of leaks on the outside of the ISS. However, this system is designed to specifically detect leaks in the coolant system, and it can only detect them from the outside of the vessel. While this is useful for finding and sealing leaks in this circumstance, there may be other types of leaks going undetected or unlocated.

The team will have guidance from NASA TSGC Sponsor, George Salazar, and faculty advisor, Dr. Richard Compeau throughout the duration of the project planning, implementation, and testing. The work to complete the project will take place either at Ingram Hall Maker Space at Texas State University or the homes of the members of Team Sonus. The team is planning on having a 90 second poster pitch available for Texas State University’s Senior Design Day on December 3, 2021. The product’s expected completion date is March 23, 2021, in anticipation of the NASA TSGC Showcase in April.

2. Product Features

The top-level block diagram was drawn by Mason Huebner, description written by Jessie Smith.

The top-level diagram of our system is shown in Figure 1. The system will use an array of 6 MEMS microphones to detect both ultrasonic anomalies and the human voice. Using 6 MEMS microphones will give us the capability of pursuing the stretch goal of anomaly localization in 3 dimensions through triangulation. Analog hardware will filter and amplify the sound detected by the MEMS microphones. The resulting clean signal will then be polled by the microcontroller unit (MCU) via the analog-to-digital converter (ADC), from there digital signal processing (DSP) will be done in software to determine which portions might be voice or ultrasonic frequencies. Other inputs include a rotary encoder with a button to control the volume of the voice audio output and to toggle the voice communication; a button to silence the auditory alert; and a power switch. The outputs include a speaker for the auditory alerts and voice audio out, LED indicators for visual alerts, and an RGB LCD which will display visual alerts, and the state of the system.

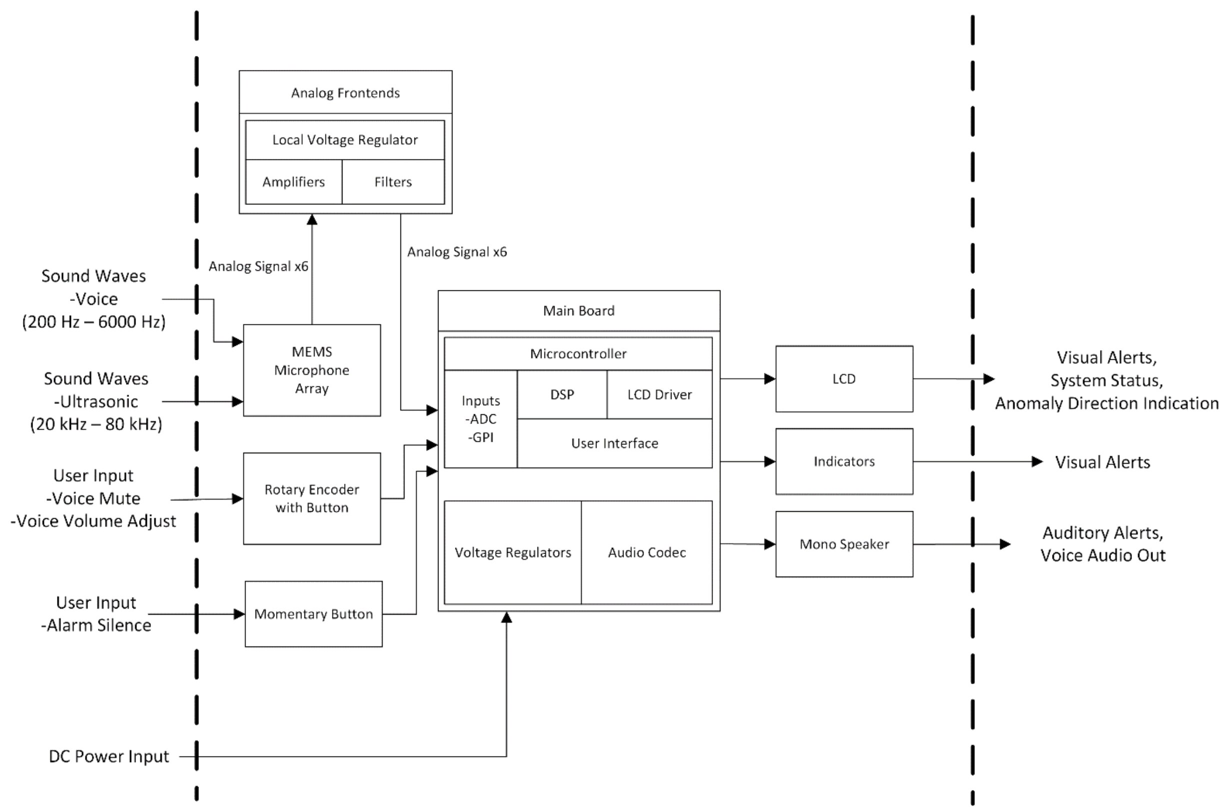

Figure 1: Top-Level Block Diagram

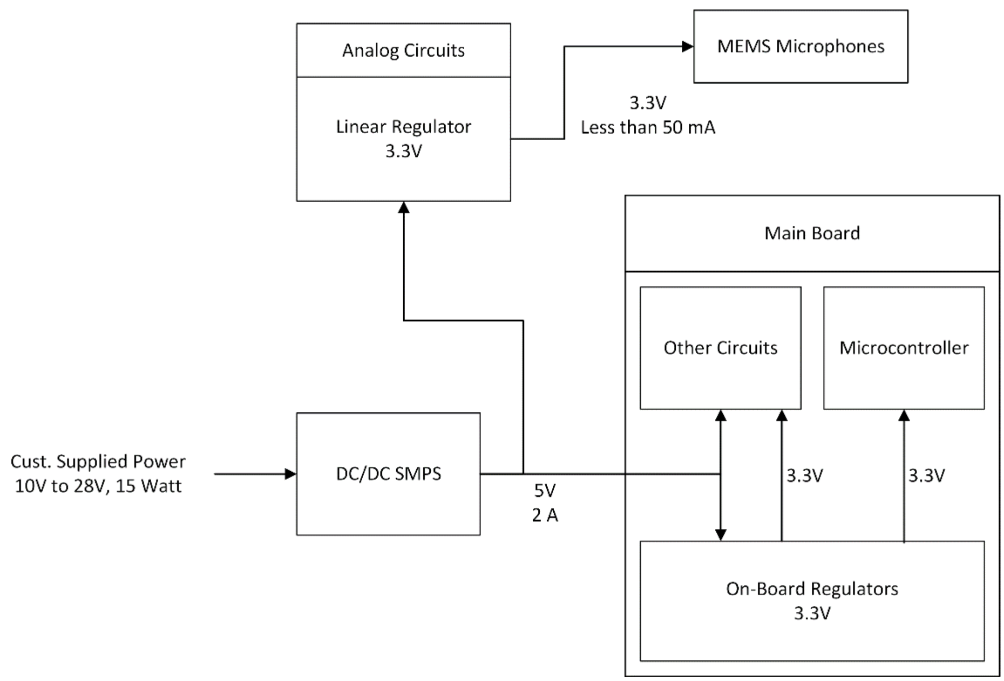

Figure 2: Power Distribution Block Diagram

Feature 1: Omnidirectional Anomaly Detection

This section was written by Mason Huebner

The omnidirectional detection system will make use of the microphone array to monitor audio emissions in the space around it while providing complete coverage with minimal dead zones. Audio emissions in the ultrasonic range are associated with air or gas flow through an orifice of some type, whether that be a machined hole, a crack, or a broken seal. These emissions, or anomalies, typically indicate a failure, and detection of such events will cause the system to produce an alert to the crew. Transient events will not trigger the alert to limit the number of false alarms, since initial testing has revealed that many common tasks, such as sniffling or rubbing two objects together, can cause ultrasonic emissions.

Analog signals from each microphone will be conditioned with gain and anti-aliasing filtering for the ADC. The sampling rate of each channel will be sufficient to capture audio frequencies in excess of 80 kHz, providing data across the audio spectrum where ultrasonic emissions from leaks are expected to occur. This spectrum data will be periodically calculated and analyzed, with processing done on samples from all channels in the same time frame. A fast Fourier transform (FFT) will be calculated for each channel, producing signal magnitude data for many frequencies across the spectrum, allowing for differentiation between events and sensitivity based on signal components, rather than the total energy.

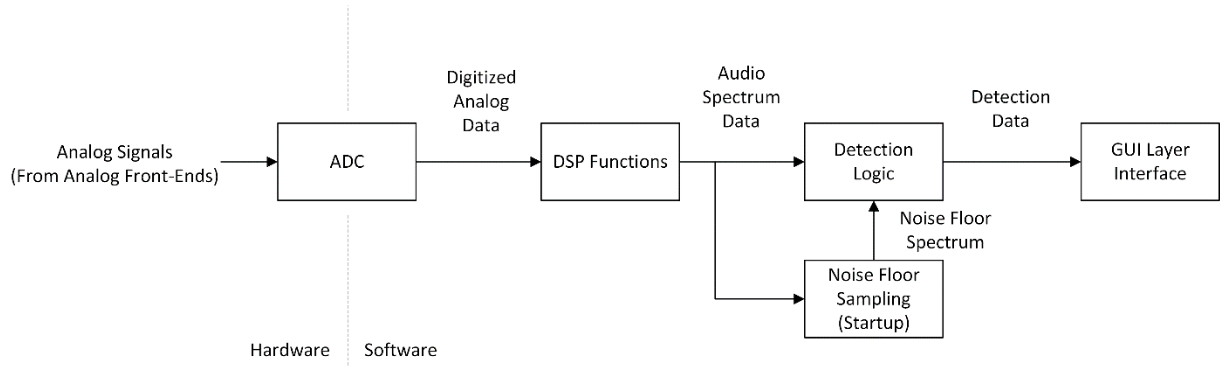

Figure 3: Anomaly Detection Process Flow.

Since detection is based on digital signal processing and the FFT, the detection threshold will also be based on the FFT. System startup will include sampling the spectrum of the environment using all microphones and determining the noise floor based on FFT data. The detection threshold will then be an offset from this noise floor, enabling the highest sensitivity possible on static system installations while ignoring existing environment noise, although overall sensitivity will still depend on existing sources. Figure 7 demonstrates existing environment noise for a subset of two microphone channels.

Feature 2: Hands-Free Voice Communications

This section was written by Nicholas Garrard

The hands-free voice communication system will be using the same array of MEMS microphones. This is the second use of the MEMS microphone array. A wideband audio signal will be detected by the MEMS array. The analog output will be passed to the microcontroller. The wideband signal will be filtered only to allow frequencies in the human vocal range to pass. The filtered audio signal will be passed to the localized speaker, where the voice communications will be played. A physical switch must be switched to "on" for hands-free communication to be enabled. Additionally, a rotary encoder will be used to adjust the volume of the output voice.

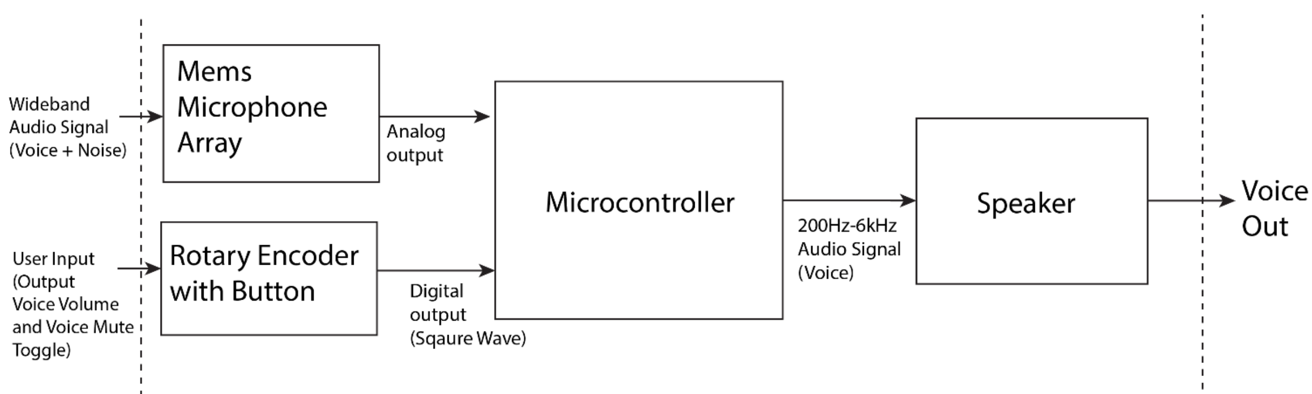

Figure 4: Hands-Free Voice Communication

Feature 3: Auditory and Visual Alerts

This section was written by Olivia Salazar-Mendez

When the system detects an anomaly, it will react with auditory and visual alerts. As referenced in Feature 2, a voice detected on the microphones will be amplified onto a local speaker. If the anomaly detected is in the ultrasonic range, it will be prioritized, an alert will be played on the local speaker at repetition rate of 1 Hz to alert the crew. As the sound pressure level of the ultrasonic frequency increases, the dB of the alarm will increase until a max volume of 80 dB is reached. The alert will continue to sound until a crew member manually disables it.

The system will also use flashing LED lights to show that an ultrasonic anomaly is detected. The system's LCD display will describe the nature of the alert.

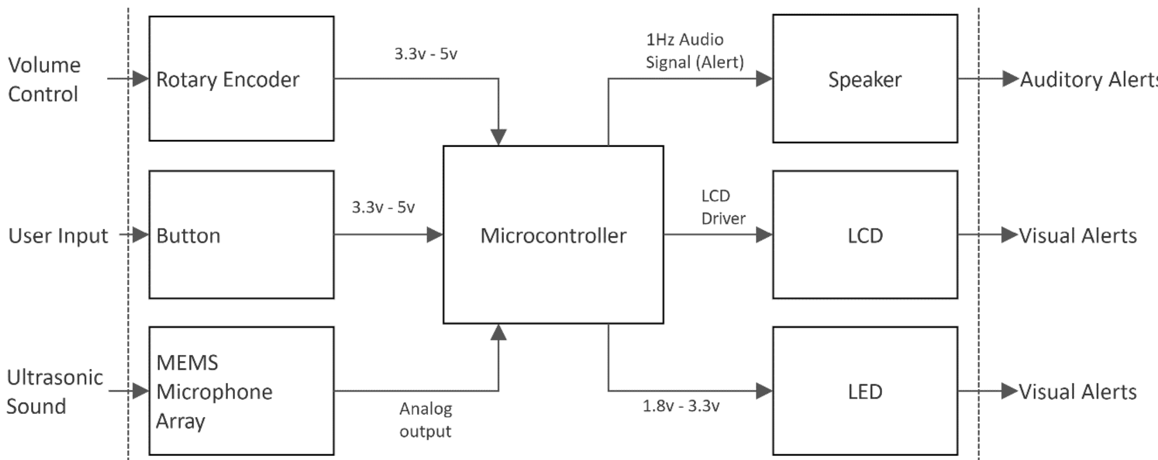

Figure 5: Auditory and Visual Alerts

Feature 4: User Interface

This section was written by Jessie Smith

As shown in Figure 6, the user interface will be composed of an RGB LCD which will display the graphical user interface (GUI) driven by the microcontroller, alert LEDs, a rotary encoder with a button to control the volume of the voice audio out and to toggle the voice communication, a button to switch off the audible alert, and a power switch. The proposed layout of the user interface is shown in Figure 6.

The GUI will display a flashing text warning if an ultrasonic anomaly is detected; furthermore, it will flash green, yellow, or red depending on the magnitude of the ultrasonic signal in tandem with the alert LEDs and auditory alert. The state of the voice communication toggle and volume will also be displayed on the GUI. If we reach our stretch goal of anomaly localization, the predicted direction of the detected ultrasonic signal will be displayed on the GUI.

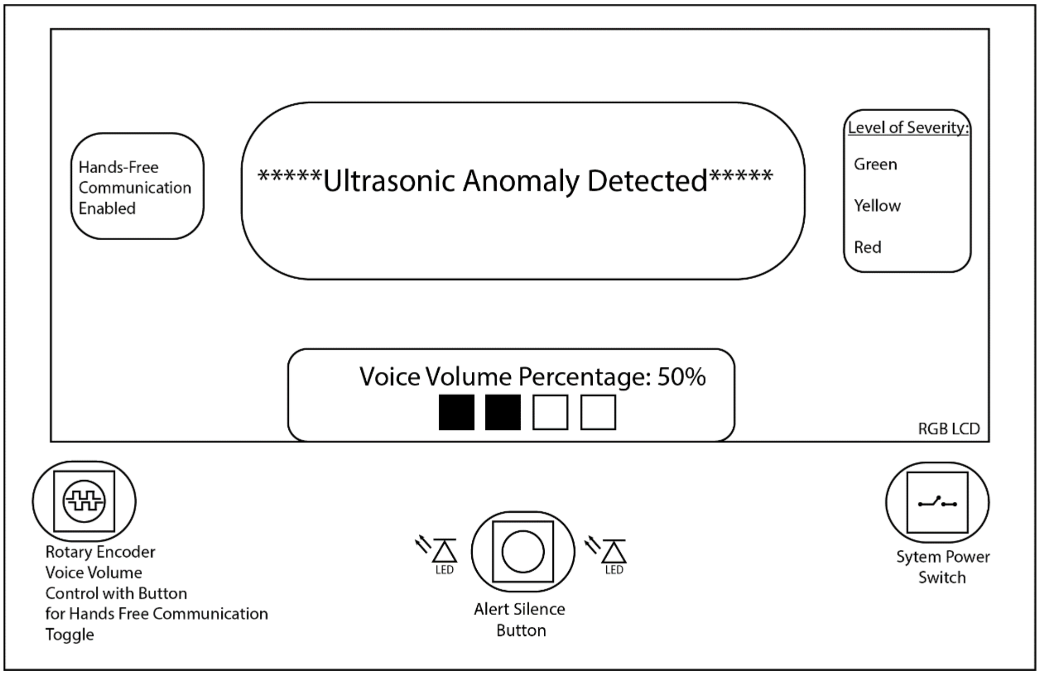

Figure 6: User Interface Concept.

Feature 5: (**STRETCH GOAL**) Direction Indication for a Detected Anomaly

This section was written by Mason Huebner

Once an anomaly is detected, the same FFT spectrum data will be used to give the user an approximate vector from the microphone array to the source of the anomaly, relative to the array. The microphone array will be structured in such a way as to facilitate the comparison of spectrum data between pairs and determine the direction of a source. Source direction can then be utilized by the user to locate the anomaly quickly and take appropriate action.

Figure 7 is a visual representation of one such comparison between microphones. This figure shows two microphone channels with opposite orientations, facing 180 degrees apart on the same axis. Peaks in the spectrum data show existing environment noise, and asymmetric peaks between the two channels demonstrate one dimensional directionality. A synthetic noise source at 40 kHz produces peaks on both signals. By comparing the frequency magnitudes between microphones direction can be approximated. Magnitudes which are close to identical for each channel are either noise floor or sources radial to the axis of the microphone ports, exposing both equally. Select frequencies where the magnitude shown by each microphone is different, such as at 40 kHz and 78 kHz in the figure, imply that the source is closer to or in the direction of the microphone with the higher magnitude. Multiple comparisons between different microphone pairs will allow the direction to the source to be determined and indicated to the user.

Source direction will be communicated to the user via the GUI. If the source cannot be determined, as in the case of environment characteristics causing multipathing to the microphone array, or a strong signal source causing signal saturation, a lack of direction determination will be communicated instead.

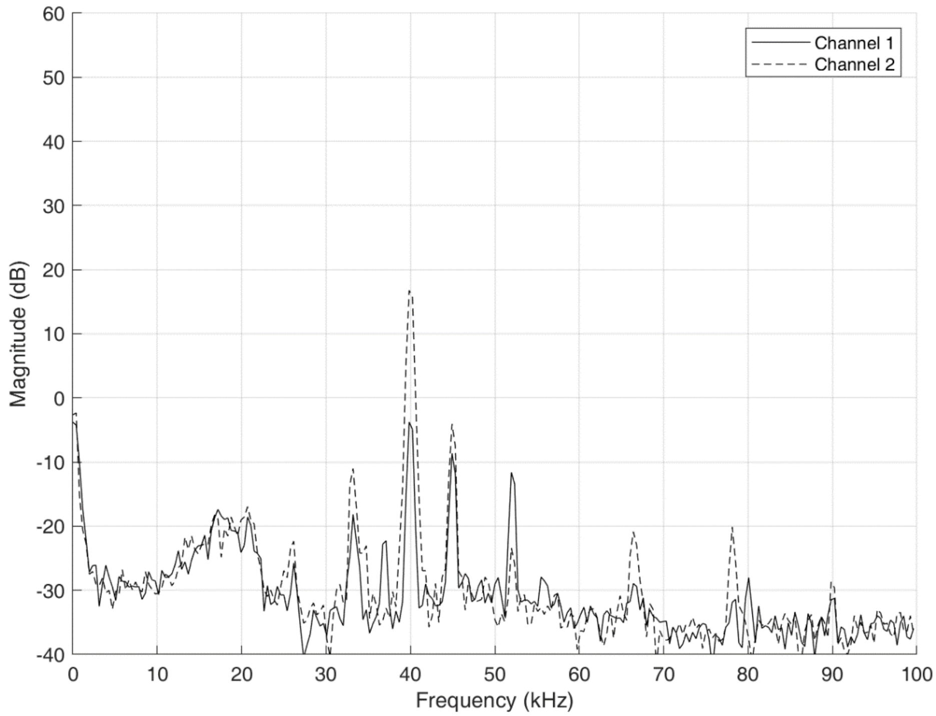

Figure 7: FFT Spectrum Data. Shown for two opposing microphones, implying directionality.

3. Project Plan

This section was written by Nicholas El-Takach.

To help split the work and to create a more efficient workflow the team has been split into two sub-teams, hardware, and software. The hardware team is led by Nicholas Garrard and includes Olivia Salazar-Mendez and Nicholas El-Takach. The software team is led by Jessie Smith and includes Mason Huebner.

In addition to the 2 sub-teams, each team member has been assigned subsystems to oversee and take responsibility for within those teams. Firstly, Mason will oversee the digital signal processing and the software-hardware layer. Olivia will oversee the MEMS microphone array, the arrays amplification, and the overall system power. Jessie will oversee the user interface system. Nicholas G. will oversee the creation of a test system as well as the final hardware assembly of the project. Lastly, Nicholas E. will oversee the physical filtering of the signals picked up by the MEMS microphone array as well as the chassis for the project.

To make communication and collaboration as efficient and effective as possible, the team will be using Microsoft Teams to communicate and Microsoft SharePoint to share and edit documents with each other. The team will have weekly meetings with our faculty advisor, Dr. Compeau, and our D2 mentor team. The team will also be having biweekly meetings with our sponsor, Mr. Salazar. These meetings will ensure that all parties involved in the project remain on the same page.

The table below lists all the major action items necessary to complete the project. Each item may be worked on by more than one team member, however, the listed designated responsible individual (DRI) is responsible for that task's completion.

Task	DRI	Start Date	End Date	Duration (Days)	Percent Complete
Document & Milestone Preparation					
TSGC Level 1: Profile, Photos, and Patch	Nick E.	8/23/2021	9/24/2021	32	100.0%
Statement of Work	Nick E.	9/13/2021	10/6/2021	23	91.3%
Prelim Project Plan	Nick E.	9/25/2021	10/15/2021	20	45.0%
TSGC Level 2: Midterm Report	Nick E.	10/6/2021	10/22/2021	16	0.0%
SD/ TSGC Level 3: Poster & Video	Nick E.	10/15/2021	11/12/2021	28	0.0%
Product Specification	Nick E.	10/16/2021	12/1/2021	46	0.0%
TSGC Level 4: Showcase	Nick E.	11/1/2021	11/15/2021	14	0.0%
Senior Design Day	Nick E.	11/1/2021	12/3/2021	32	0.0%
TSGC Level 5: Final Report	Nick E.	11/3/2021	12/3/2021	30	0.0%
2nd Semester Poster/Video	Nick E.	3/21/2022	4/8/2022	18	0.0%
TSGC Spring Showcase	Nick E.	3/30/2022	4/15/2022	16	0.0%
Research & Decide					
MEMS Microphone	Olivia	8/23/2021	9/10/2021	18	100.0%
Microcontroller	Jessie	8/23/2021	9/17/2021	25	100.0%
Signal Processing	Mason	8/23/2021	9/17/2021	25	100.0%
Testing Methods	Nick G.	8/28/2021	10/11/2021	44	84.1%
Power	Olivia	9/17/2021	10/11/2021	24	70.8%
Amplifiers	Nick E.	9/17/2021	10/11/2021	24	70.8%
Filters	Nick E.	9/17/2021	10/11/2021	24	70.8%
Design & Develop					
Digital Signal Processing	Mason	10/11/2021	11/8/2021	28	0.0%
Analog Amplification	Olivia	10/11/2021	11/8/2021	28	0.0%
Analog Filtering	Nick E.	10/11/2021	11/8/2021	28	0.0%
Power System	Olivia	10/11/2021	11/8/2021	28	0.0%
Test System	Nick G.	10/11/2021	11/8/2021	28	0.0%
Alarm/Annunciation System	Nick G.	10/11/2021	11/8/2021	28	0.0%
Concept for GUI	Jessie	10/11/2021	11/8/2021	28	0.0%
Concept for Physical UI	Jessie	10/11/2021	11/8/2021	28	0.0%
Chassis	Nick E.	10/11/2021	11/8/2021	28	0.0%
Implementation					
Power	Olivia	1/19/2022	2/11/2022	23	0.0%
Analog Filtering/Amplification System	Nick E.	1/19/2022	2/11/2022	23	0.0%
User Input/output	Jessie	1/19/2022	2/11/2022	23	0.0%
Alert/Annunciation System	Nick G.	1/19/2022	2/11/2022	23	0.0%
Digital Signal Processing	Mason	1/19/2022	2/11/2022	23	0.0%
Chassis	Nick E.	1/19/2022	2/11/2022	23	0.0%
System Integration - Hardware	Nick G.	2/14/2022	2/21/2022	7	0.0%
System Integration - Software	Jessie	2/14/2022	2/21/2022	7	0.0%
System Integration - Full System	Nick E.	2/14/2022	2/21/2022	7	0.0%
Testing					
Ultrasonic Filtering/Detection	Nick E.	2/28/2022	3/23/2022	23	0.0%
Speech Filtering/Detection	Nick G.	2/28/2022	3/23/2022	23	0.0%
Latency of User Interface	Jessie	2/28/2022	3/23/2022	23	0.0%
Alert/Annunciation Functionality	Nick G.	2/28/2022	3/23/2022	23	0.0%
Overall Power Draw	Olivia	2/28/2022	3/23/2022	23	0.0%
Digital Signal Processing	Mason	2/28/2022	3/23/2022	23	0.0%
Overall Product	Nick E.	3/23/2022	3/30/2022	7	0.0%

Table 1: Project Plan Schedule Table

Upon completion of the project, all relevant design files (source code, schematics, etc.) and test data needed to reproduce or continue development of the project will be sent to our sponsor, and a demo of the system will be provided.

4. Sponsor Support Elements

This section was written by Nicholas Garrard

The team received the design topic from the Texas Space Grant Consortium. The topic outlines the project requirements and deadlines. Our sponsor, George Salazar, will provide the team guidance throughout the project. The team and Mr. Salazar agreed to meet on a virtual bi-weekly basis.

Mr. Salazar will provide the team with guidance with his vast engineering experience at NASA. Currently, no other additional elements are needed from the sponsor.

Sponsor Support Elements		
Element	First Needed	Needed Until
Bi-weekly meetings with George Salazar	9/20/21	5/2/22

5. Approvals

The signatures of the people below indicate an understanding in the purpose and content of this document by those signing it. By signing this document, you indicate that you approve of the proposed project outlined in this Statement of Work and that the next steps may be taken to create a Product Specification and proceed with the project.

Approver Name	Title	Signature	Date
Nicholas El-Takach	Project Manager		
Jeffery Pearce	D2 Project Manager		
Dr. Compeau	Faculty Advisor	CRC	10/5/21
Mr. Salazar	Sponsor		
Mr. Welker	Instructor		

Section	Author	Word Count
Sec 4, Feature 2, Figs 4 & 6	Nicholas Garrard	178
Sec 5 Intro, Feature 4, Figs 6, table 1	Jessie Smith	324
Features 1 & 5, Figs 1,2,3, & 7	Mason Huebner	603
Sec 1, Feature 3, Fig 5	Olivia Salazar-Mendez	467
Sec 3, table 1	Nicholas El-Takach	308