Low-Cost Data Acquisition Project for Acoustic Emissions

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Industrial manufacturing processes depend heavily upon both the condition of the machine and the health of tools. Failure of tools can affect both plant downtime and quality of the products. Monitoring these conditions and diagnosing faults are an important component of preventative maintenance systems which decrease maintenance costs, improve quality of the product and increase the longevity of the machine. Additionally, monitoring tool conditions such as wear and failure are an important part of manufacturing. A solution is to use non-invasive sensors such as acoustic microphones to remotely detect manufacturing process parameters. Acoustic signals produced by these machines can be used to monitor spindle speed, depth of cut, and feed rate to ensure optimal performance.

Off-the-shelf data acquisition systems exist for acquiring multiple simultaneous analog input channels. One such PC-based system is the National Instruments PXI platform. These systems can be programmed using LabVIEW, C/C++, or Python. However, these systems can be very expensive. Thus, there is a need for low-cost data acquisition systems with similar essential capabilities. The goal of this paper is to show the design of a hardware/software system with fractional cost compared to a commercial system for collecting and displaying acoustic signals from a spherical microphone array consisting of 32 microphones. The signals from all microphones will be collected simultaneously, achieving a sample rate of at least 48 kHz and at least 10-bits of resolution for each microphone. A Python GUI will be used to control the data collection process and display the data (both time and frequency domain) from each microphone. A detailed testing procedure with results will be shown to validate the system's performance. An example of such a system was designed by students in a project-based course, suitable for senior-level students in electrical and computer engineering and engineering technology programs. This paper will show detailed engineering requirements, schematics, software flowchart, and testing results for this system.

Background and Significance of Acoustic Emissions

Although manufacturing monitoring methodologies and signal processing techniques have enabled engineers to optimize manufacturing process parameters, process faults and anomalies can be difficult to predict. Conditioning monitoring techniques and advanced real-time signal processing algorithms have been implemented for monitoring single machines on a shop floor [1]. An important component in these systems is the type of sensor utilized. The primary signals collected by these sensors include force, vibration, and sound [2-3]. These signals can be detected by invasive sensors, which can be impractical for legacy machines and costly [4-5]. Thus, noninvasive methodologies for data collection and signal processing are of interest for this research work. Acoustic signals (AS) have proven to be used for a wide range of applications [2, 6-9]. The sound signals of machines in a manufacturing environment contain information regarding deformation, fracture, chip entanglement, crack formation, etc. [6, 8, 10-11]. Additionally, microphones can be easily implemented in manufacturing environments. Using microphones for AS data collection and implementing advanced data analysis techniques represent a robust non-invasive technique for predictive machine maintenance and for predicting machine process parameters. Acoustic signals using microphones were previously obtained during a machine lathe operation. These signals were applied with transfer learning to a deep neural network for predicting machine process parameters (e.g., spindle speed, feed rate, and depth of cut) with an accuracy of approximately 96% [12]. However, this methodology may be limited in predicting process parameters from multiple machines running simultaneously, since it utilizes AS from only one microphone. Additional research expanded this work by utilizing all 32 microphones on a spherical array for predicting process parameters from one machine [13].

Acoustic Camera System

An acoustic camera system was previously purchased and consisted of the following [14].

- 32-element spherical microphone array
- National Instruments PXI Chassis
- Two National Instruments microphone cards
- National Instruments ExpressCard 8360
- Acoustic analysis software

The microphone array consists of 32 Panasonic microphone elements (WM61) arranged in a spherical pattern for 3D scanning. The array is connected to a National Instruments 5-slot PXI controller (PXI-1033) [15]. Two National Instruments microphone cards (PXI-6250) occupy 2 slots of the PXI chassis [16]. Each card has 16 analog input channels configured for 48 kHz sampling with 16 bits of resolution. Thus, all 32 microphone elements are simultaneously sampled. The PXI chassis is connected to a laptop through an ExpressCard interface (8360) [17]. Acoustic analysis software (NoiseImage) for the laptop is used to both data collection and processing [14].

Applications for this system consist of the following.

- Operational characteristics of multiple simultaneous industrial machines (machine ON/OFF, cutting ON/OFF, spindle speed, etc.)
- Tool wear and tool failure on industrial machines
- Condition-based maintenance for industrial machines and other equipment (e.g., aircraft systems, etc.)
- Quenching
- Casting
- Noise in vehicle interiors

Much of the hardware for the above acoustic camera system is obsolete. The National Instruments PXI-1033 chassis is no longer available and driver support for recent versions of Windows is no longer available. The ExpressCard interface is largely obsolete in newer laptops. National Instruments does offer an upgrade to the PXI chassis that has an integrated Thunderbolt controller (PXIe-1083) [18]. The same microphone cards (PXI-6250) can be used in this chassis. However, the upgrade to the newer PXI chassis can be prohibitive without research funding. Thus, there is a need for low-cost data acquisition systems that offer similar essential capabilities. The goal of this paper is to provide such a system designed by students in a project-based course.

Senior Design Project Course

This senior design experience aligns closely with project-based learning (PBL), a pedagogical model shown to reinforce core engineering skills such as systems thinking, collaborative problem-solving, and iterative design. Students worked on a multi-phase challenge integrating hardware, software, and signal processing while navigating constraints in real time. PBL is particularly effective in engineering technology programs, where hands-on learning and system-level integration are essential to professional preparation. Prior ASEE studies have shown that well-scaffolded project-based activities increase student motivation, deepen conceptual understanding, and help students transfer classroom theory to real-world applications [19], [20]. Framing this project as PBL also supports faculty in meeting ABET learning outcomes while preparing students for both technical and team-based challenges in their careers.

Students in electrical and computer engineering and engineering technology programs are often required to complete a senior design project for completion of their degree. This can consist of a one or two-semester course sequence. One example is a 1-credit fall semester course and a 3-credit spring semester course in an electrical and computer engineering technology program. The fall semester course is primarily designed to introduce student teams (consisting of 2-4 students) to their projects and have them complete some of the project documentation. The spring semester course is primarily designed for student teams to complete their project requirements. An overview of some important requirements for each project includes the following. More details are provided in an open educational resource available for reference [21].

- Requirements specification
  - Needs and objectives of project
  - Background and technology survey
  - Marketing requirements
  - Objective tree
  - Ranking of needs
  - Engineering requirements and justifications
- Design specification
  - Functional decomposition design
  - Design alternatives
  - Software flowcharts
  - Design calculations
  - Schematics
  - Parts list
  - Design justification
- Project management plan
  - Work breakdown structure
  - Gantt chart
  - Development cost estimates
- Qualification specification
  - Table listing:
    - Each engineering requirement
    - If a test is needed

        - How compliance will be determined
        - Accept/reject criteria
    - Test procedure for each test
    - Results for each test

Projects are structured to reinforce system-level integration, verification planning, and documentation skills expected of graduating seniors. Students demonstrate competencies in requirements development, hardware and software co-design, and validation planning consistent with ABET-aligned learning outcomes.

For each project, student teams are provided with project descriptions. One example from Fall 2024-Spring 2025 is the acoustic data collection system. The project description is below.

> *Students will design a hardware/software project with the end goal of collecting and displaying acoustic signals from a spherical microphone array consisting of 32 microphones. The signals from all microphones need to be collected simultaneously, with a sample rate of at least 48kHz and at least 10-bits of resolution for each microphone. The project needs to be interfaced directly to the existing microphone array. Data from each microphone will be stored as a text file. A user interface will be designed to start the data collection process and display the data (both time and frequency domain) from each microphone.*

Acoustic Data Collection System Senior Design Project

This paper focuses on selected design artifacts and results most relevant to engineering education, with full project documentation available upon request. One team of two Electrical and Computer Engineering Technology students was placed on the senior design project. The engineering requirements specify the technical needs of the project and are shown in Table 1. These were determined by the student team in the fall semester. Each engineering requirement is linked to one or more marketing requirements, and a justification is provided. The marketing requirements indicate what the product needs to do and are specified in the language of the customer (i.e., short, action-oriented phrases that are non-technical). The marketing requirements are numbered and are shown at the bottom of Table 1. Each engineering requirement needs to be unambiguous and verifiable, since an appropriate test will need to be determined for the qualification specification. The qualification specification is determined in the spring semester.

The design specification provides a functional decomposition, where the project is divided into submodules that can be described with inputs, outputs, and function. These submodules are interconnected together to form the design architecture. The design architecture for this project is shown in Figure 1. The submodules can be further subdivided until realizable components can be found. As shown in Figure 1, two Teensy microcontrollers were used in order to achieve the required sample rate [22]. These microcontrollers control the four analog-to-digital converters (ADCs) using the Serial Peripheral Interface (SPI) [23-24]. Each ADC has 8 analog input channels with 16 bits of resolution. The analog input channels are grouped to enable high-speed, simultaneous, signal acquisition.

Analog signal conditioning is provided between the connector to the microphone array and the

ADCs. A schematic for each signal conditioning circuit is shown in Figure 2. The circuit utilizes an op-amp with resistors and a capacitor designed to remove any DC offset from the microphone outputs and provide voltage amplification [25].

An image for the prototype of the hardware design of the data acquisition project is shown in Figure 3. A perforated board (perfboard) was used to aid in prototyping the hardware design. This image shows the two microcontrollers and the four ADCs. A second perfboard (not shown) contains the signal conditioning circuits and analog components.

The student team also completed a printed circuit board (PCB) layout (using KiCad) of the hardware design, and this is shown in Figure 4 [26]. Due to time constraints, the student team was unable to have the PCB fabricated.

As visible in Figure 3, the microcontrollers have USB host ports for connections to laptop USB ports. A flowchart for the laptop Python program is shown in Figure 5. The software includes a graphical user interface (GUI) for use on a Windows 11 operating system and provides an intuitive platform to configure system settings, including recording duration and file storage paths. After completing a data recording session, users can visualize the results by selecting individual microphones from the array. The data from these selected microphones can be stored to disk and graphed in both time-domain and frequency-domain using the Fast Fourier Transform (FFT).

An image of the GUI software program is shown in Figure 6. The GUI includes tabs for home, viewing results, and saving results to disk. The home screen allows the user to select the COM ports, selecting the microphones for data collection, recording time, and buttons for documentation and starting the recording.

Table 1. Project Engineering Requirements

Marketing Requirements	Engineering Requirement	Justification
1	Simultaneously receive acoustic signals from the 32-microphone array	Specified by sponsor
2	Collect the signals with a sample rate of at least 48kHz	Specified by sponsor
2	Receive a signal from each microphone with at least 10 bits of resolution	Specified by sponsor
4	Data from microphone needs to be stored as a text file	Data is stored for inspection
5	User interface must allow users to select which microphones they want to view or save the data from	Allows for more User control over data collected
5	User interface must have a time selection of 0-10 seconds for data collection	Eliminates excess storage for unwanted data.
3	System and interface must be compatible with windows 11	Allows for ease of use
7	Cost of the new system must be within the $250 budget	Specified by sponsor
5	User interface must have a way to specify a file path for recordings	Allows user to easily locate text files
6	User interface displays selected microphone data on a Fast Fourier transform graph	Allows the User to examine data easily

Marketing Requirements:
1. System should collect data of the 32-microphone array simultaneously
2. System has sample rate of at least 48kHz and 10-bit of resolution
3. System and software are compatible with windows systems
4. Raw data received converted to text files
5. Software has options of microphone selection, file path, and recording time
6. Software has a visual display of data
7. Cost of new system must be low

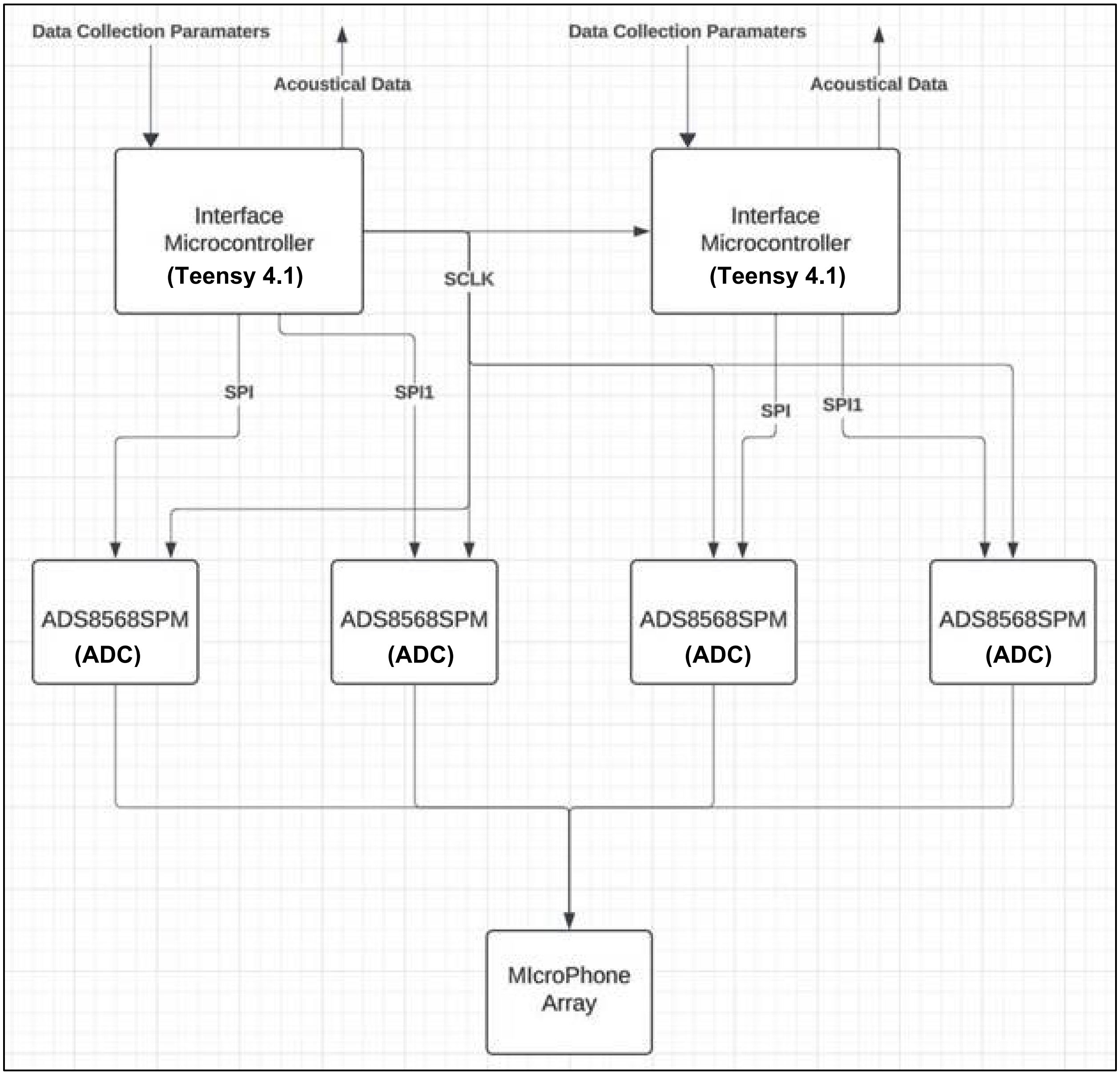

Figure 1. Hardware Architecture

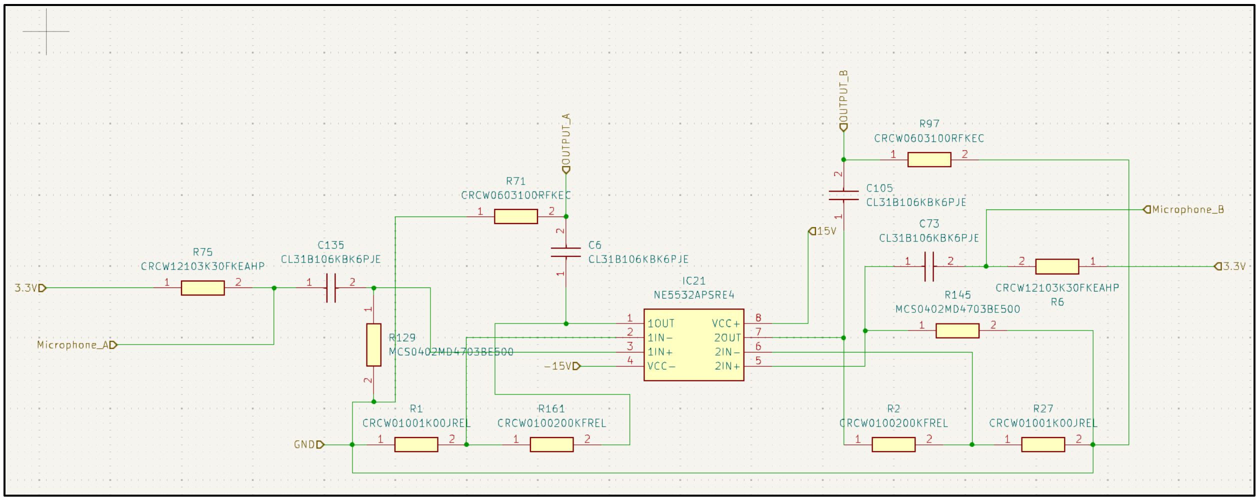

Figure 2. Schematic of Signal Conditioning Circuit

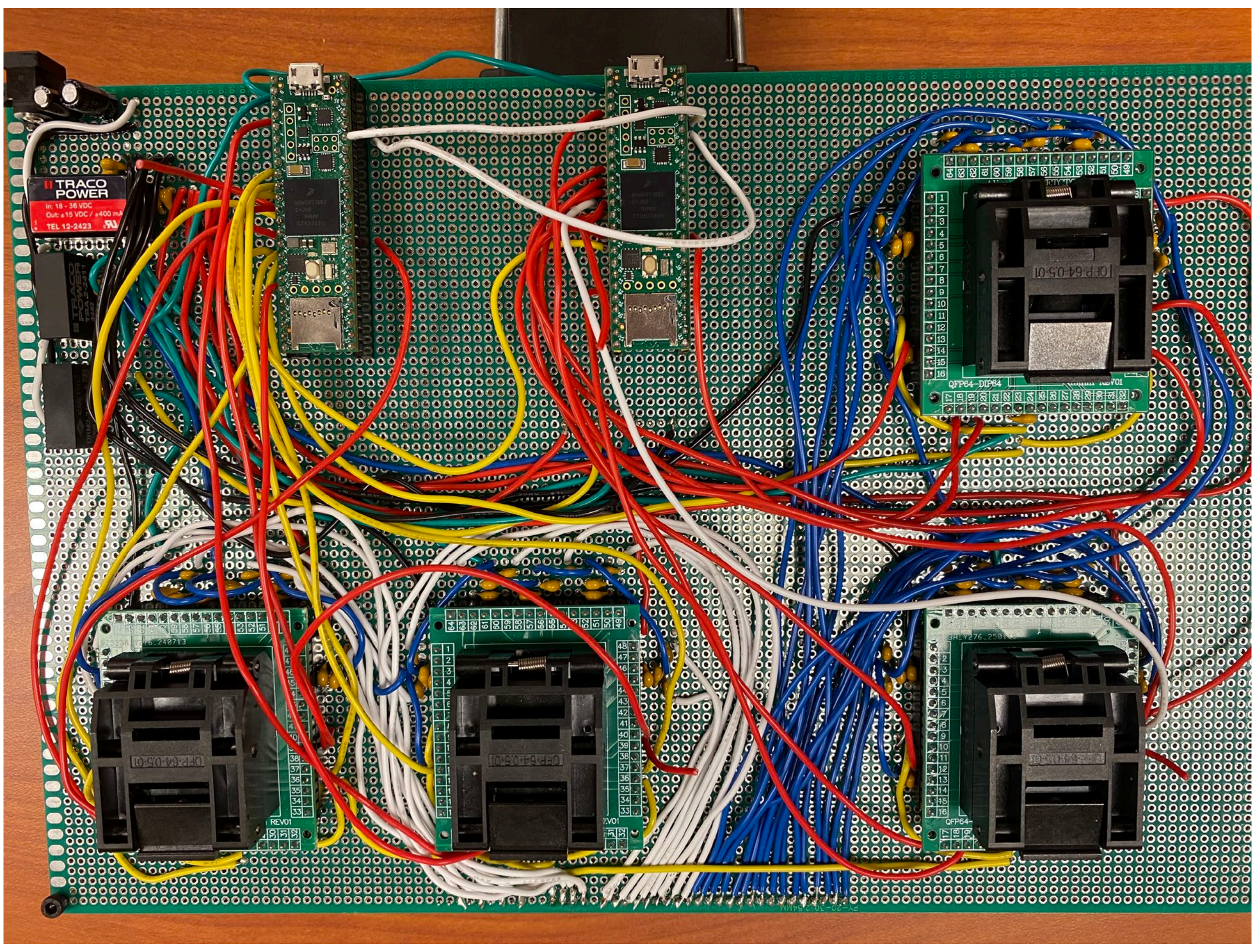

Figure 3. Image of Prototype for Hardware Design

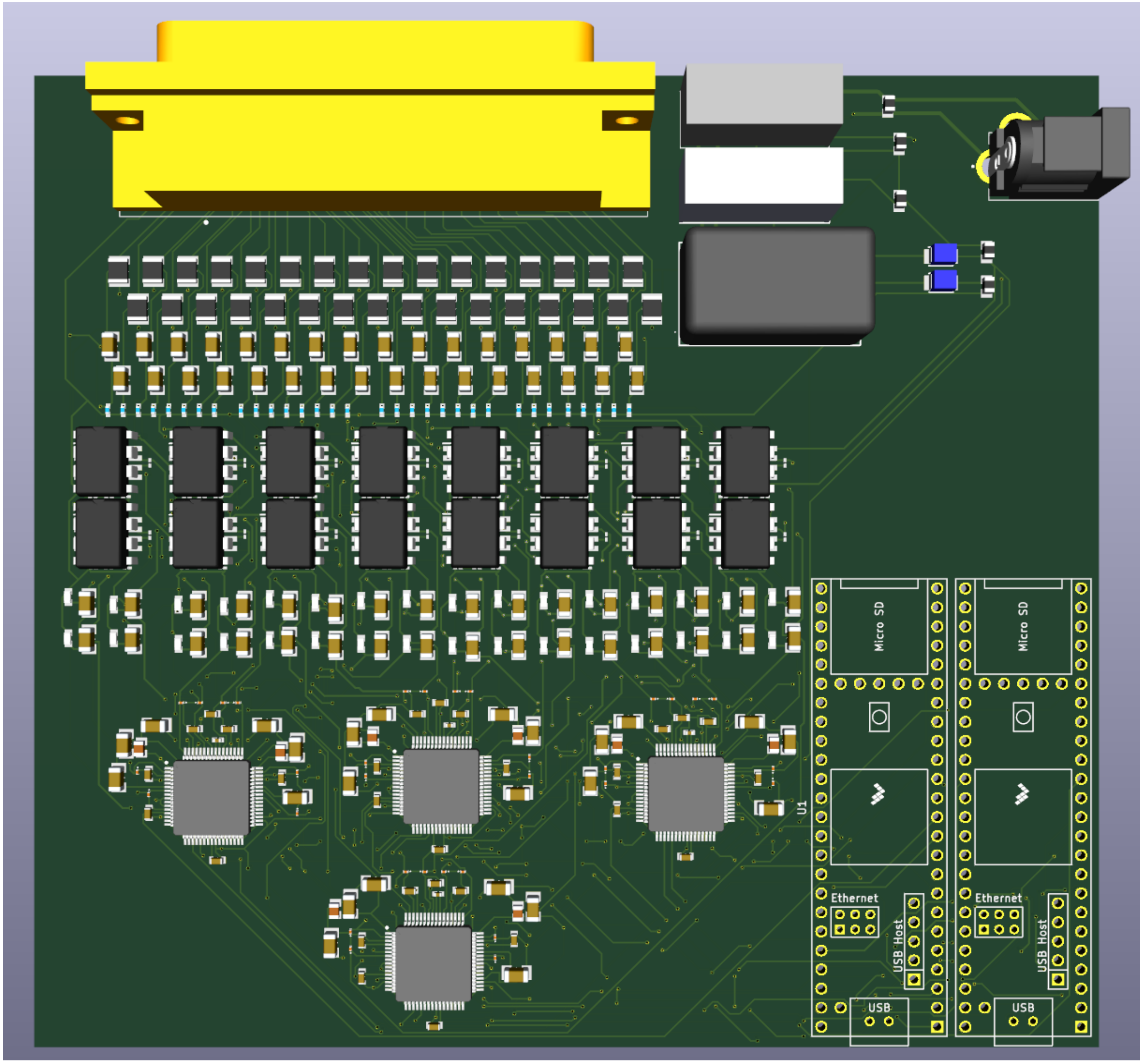

Figure 4. PCB Layout of Hardware Design

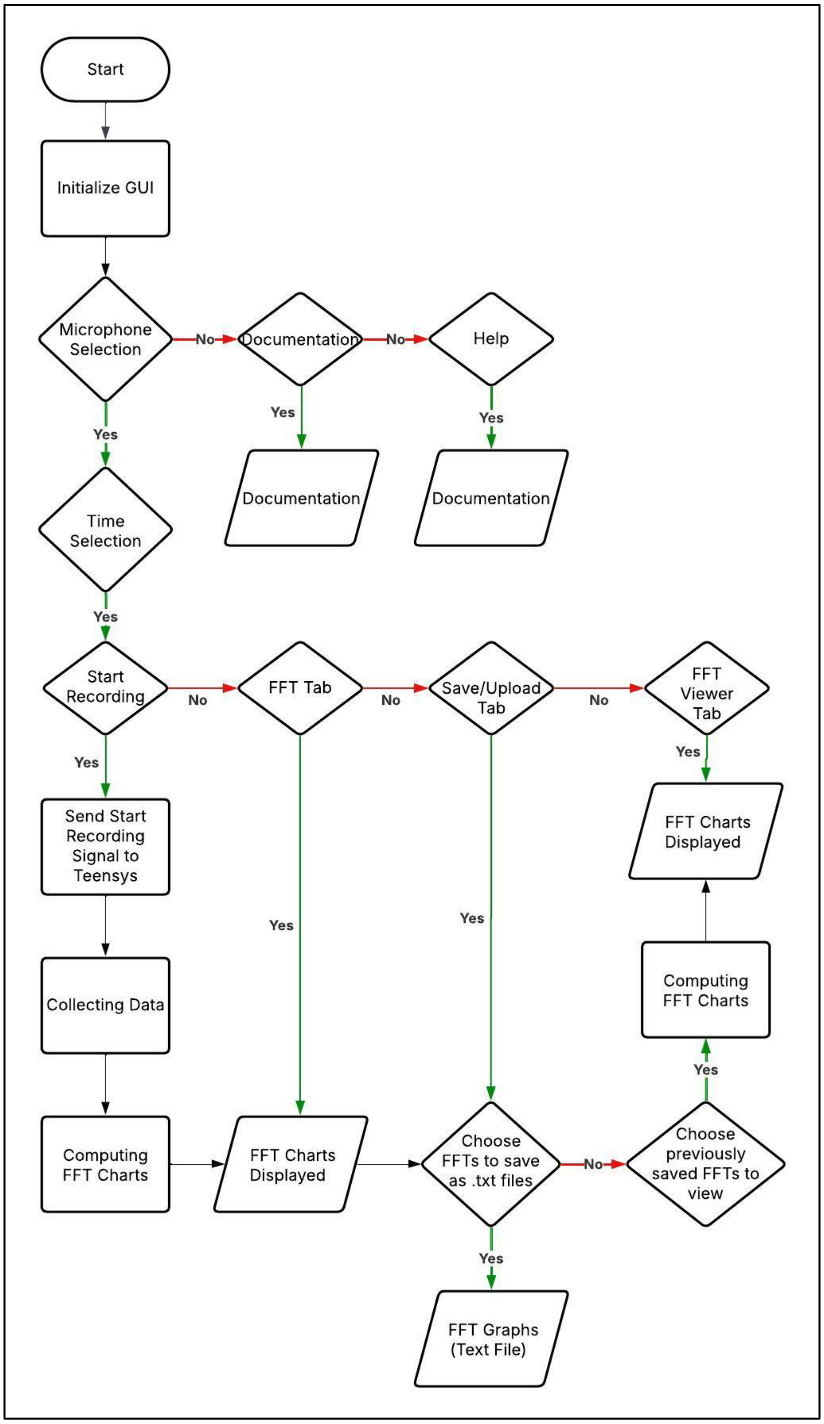

Figure 5. Flowchart of Laptop Python Software Design

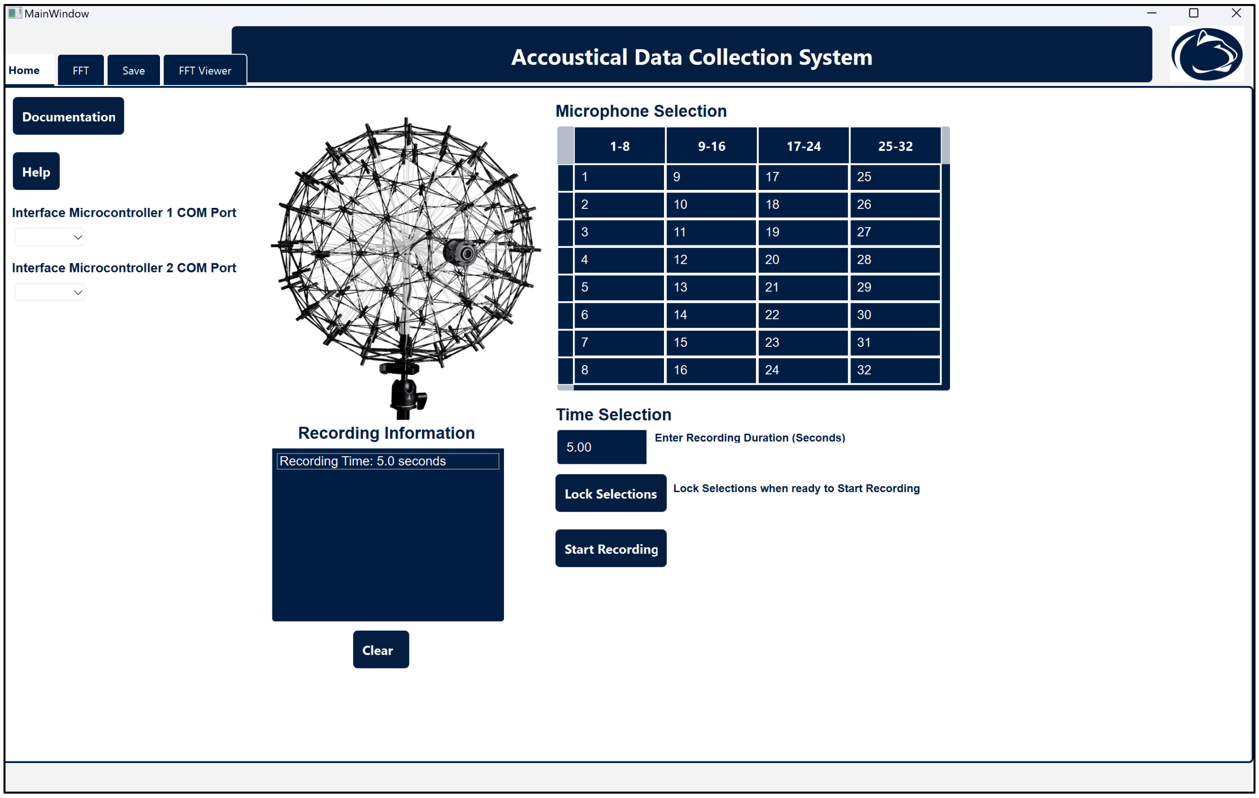

Figure 6. Image of Laptop Python GUI Home Screen

Preliminary Results from Prototype

Preliminary testing was performed by the team. The team's objective was to test for verification of the engineering requirements.

- Simultaneously receive acoustic signals from the 32-microphone array
- Collect the signals with a sample rate of at least 48kHz
- Receive a signal from each microphone with at least 10 bits of resolution
- Data from microphones needs to be stored as a text file
- User interface must allow users to select which microphones they want to view or save the data from
- User interface must have a time selection of 0-10 seconds for data collection
- System and interface must be compatible with windows 11
- Cost of the new system must be within the $250 budget
- User interface must have a way to specify a file path for recordings
- User interface displays selected microphone data on a Fast Fourier transform graph

Testing was performed by generating a tone from the team's cell phone, placing the cell phone next to a specific microphone, and executing the GUI shown in Figure 6. Most of the engineering requirements were preliminarily verified by confirming the functionality of the GUI and confirming the outputs. An example is shown in Figure 7, where both the time-domain and frequency-domain plots for microphones 6 and 12 are shown. Project expenditures were approximately \$400. Higher cost parts included 32 0.1% tolerance 200kΩ resistors, a power supply, and 4 sockets for the ADCs. However, the student team did not verify the actual sample rate nor the accuracy of the FFT results, which require future validation work. Additionally, the team needed to provide a detailed testing plan and results for various types of waveforms (e.g., sinusoidal, square wave, etc.).

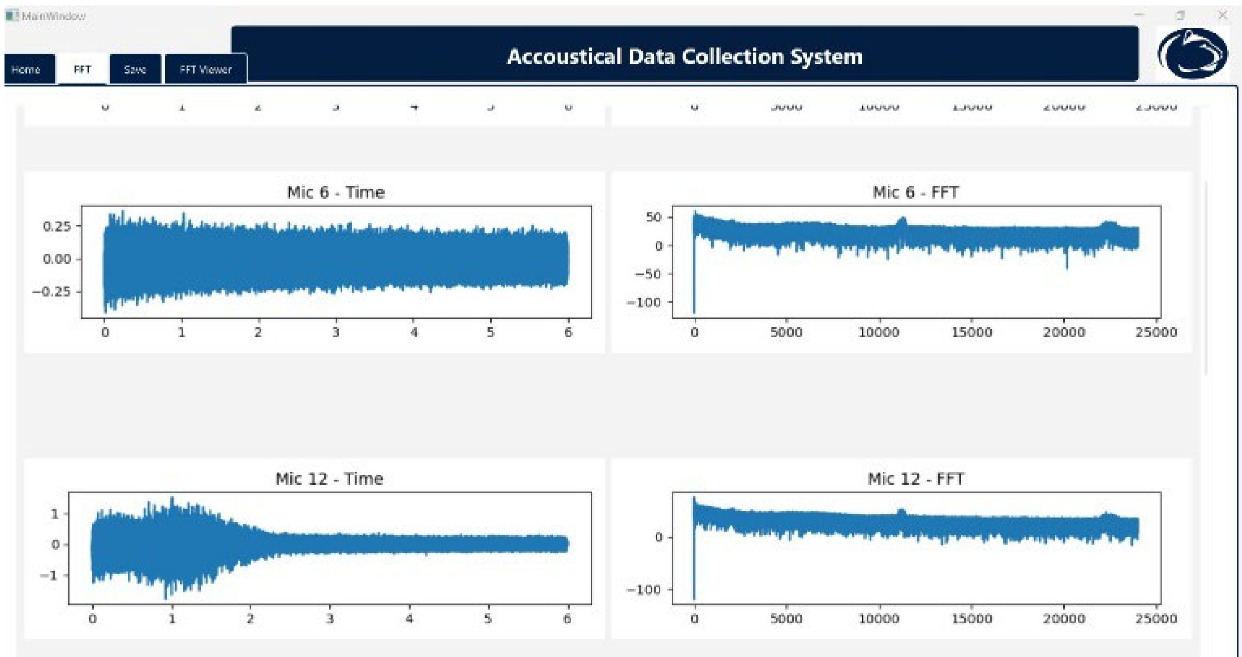

Figure 7. Image of Laptop Python GUI FFT Results

While preliminary functionality was demonstrated, full technical validation, including verification of sampling simultaneity, sampling frequency accuracy, and FFT spectral accuracy, is required to substantiate system performance.

Continuation of Acoustic Data Collection System Senior Design Project

As a result of insufficient validation of system performance and the lack of a PCB, a continuation to the acoustic data collection system was offered as another senior design project for Fall 2025-Spring 2026. The following description was provided for the students.

> *Students will design the hardware and software for an acoustic data collection system with the goal of collecting and displaying acoustic signals from an existing spherical microphone array consisting of 32 microphones. The signals from all microphones will be collected simultaneously, with a sample rate of at least 48kHz and at least 10-bits of resolution for each microphone. A prototype has already been designed that interfaces directly to the existing microphone array. However, validation of the prototype needs to occur with the possibility of a redesign if needed. The final hardware will be a PCB design. Data from each microphone will be stored as a text file. A PC user interface will be designed to start the data collection process and display the data (both time and frequency domain) from each*

microphone. A testing procedure will be designed and implemented to collect and store multiple sets of acoustic data.

A two-student team was placed on this continuation project. Validation of the prototype is ongoing.

Student Assessment

In tandem with the technical development, informal but structured assessment strategies will be used to better understand student learning outcomes and support continuous improvement. Mid- and post-project debriefs provided insights into student self-efficacy, team coordination, and problem-solving strategies under uncertainty. These methods align with PBL assessment practices in engineering education, where reflective activities, design reviews, and embedded feedback loops help evaluate not just what students produce, but how they think and work [27]. Because this assessment was integrated into regular instructional practice, it is IRB-exempt while still able to yield valuable insight into skill development and student experience. Future work may expand on these efforts through survey instruments or validated rubrics to better support longitudinal study of student outcomes.

Student assessment was performed with the original team [28]. Student assessment for the continuation project team will be conducted and incorporated in the final submission.

Summary

Acoustic signals (AS) have been used in manufacturing environments for predictive machine maintenance and for predicting machine process parameters. Off-the-shelf data acquisition systems exist for acquiring multiple simultaneous analog input channels from a microphone array. However, these systems can be very expensive. The data acquisition system shown in this paper presents a low-cost alternative system designed by students in a senior design projects course, suitable for students in electrical and computer engineering and engineering technology programs.

Although the system has not been fully validated yet, preliminary results indicate that 32 microphones can be simultaneously sampled at a rate of at least 48 kHz with at least 10-bits of resolution for a time period up to 10 seconds. These results can be displayed as a function of time and frequency and stored to disk. More testing will need to be performed for complete system validation.

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