Portable High Energy Experiment DAQ

Ethan Barnes
Sang Hoon Chung
John Sabra

CONCEPT OF OPERATIONS

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CONCEPT OF OPERATIONS
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Portable High Energy Experiment DAQ

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APPROVED BY:

Project Leader Date

Prof. Kalafatis Date

T/A Date

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1. Executive Summary

This project aims to build a device able to detect the occurrence of low blast (5 lb. charge or smaller) within a 100 ft area. Our device or The Portable High Energy Experiment Data Acquisition System (PHEE DAQ) will continuously gather real time data using a sensor array and subsequently analyze this data within a processor to identify the occurrence of an explosive event. We plan to accurately detect an explosion within 100ft by utilizing acoustic, pressure, and vibration sensors. Since this device is expected to gather data continuously, the design will be self-powered with a chargeable battery. To accommodate real time data acquisition, the microcontroller will capture the rise of the event with sampling at fast rates (2 kHz or higher). The output of the microcontroller will identify whether an explosion has occurred and will be stored onto onboard storage.

2. Introduction

The purpose of this document is to propose the design of a device capable of detecting a low blast (5 lb. charge or smaller) within 100ft. This PHEE DAQ is a system capable of gathering and analyzing data to determine occurrence of explosive event in its surroundings by using an array of sensors connected to a microcontroller unit. This system will be portable and will feature removeable data storage so that it can be recovered at any time.

2.1. Background

Terrorism and acts of violence occur daily all over the world. Currently, in places where many US troops are deployed, the risk of bombing is always inherent. Many terrorists do not use large explosives. Even the C4 we use in our favorite game Counter Strike weighs no more than 5 lbs. However, despite this, the power of these explosives is far greater than we can imagine, and they have the potential to harm many people [1]. To reduce the damage of these explosives, it is advantageous to detect these explosions and minimize their damage.

Sandia National Laboratories aims to design a portable device that can detect explosive charges that are 5 lbs. or less in size from within 100 ft. The working concept of this device is as follows: it gathers data continuously in real time, and the moment it detects a high energy event, it outputs whether it has detected an explosion. Subsequently, this data is saved in onboard storage for reference at any time.

Our team's goal is to design this device. We plan to design a device that can detect an explosive event by selecting the appropriate sensors, designing software that uses sampling, and filters so that the device can analyze the signal in real time as soon as it is detected [2]. This process will require a stable power source, removable storage that can store and utilize sufficient data, and a microcontroller integrated onto a custom printed circuit board (PCB). The portability of this design along with the versatility of its data inputs make it an optimal choice for any type of data acquisition especially high energy experiments.

2.2. Overview

The network used in this device detects the explosion of various sensors (acoustic [3], pressure [4], vibration sensor [5], etc.) connected to the microcontroller. It moves the data to the microcontroller, where the filter is coded and can be sampled in real-time for analysis. This data will be saved continuously on a removable storage device. Developing the GUI for configuring DAQ settings will give the output “quick looks” of data. The Portable High Energy Experiment Data Acquisition System (PHEE DAQ) calculates the time and the weight of the explosive. This allows the user to determine which areas explosions have been detected and pinpoint areas that need to be carefully monitored.

2.3. Referenced Documents and Standards

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[2]: Skotak Maciej, Alay Eren, Chandra Namas, “On the Accurate Determination of Shock Wave Time-Pressure Profile in the Experimental Models of Blast-Induced Neurotrauma” Accessed at https://www.frontiersin.org/articles/10.3389/fneur.2018.00052.

[3]: R. Showen, C. Dunson, G.H. Woodman, S. Christopher, T. Lim, S.C. Wilson, Locating fish bomb blasts in real-time using a networked acoustic system, Accessed at https://doi.org/10.1016/j.marpolbul.2018.01.029.

[4]: Ma, Xuejiao, Deren Kong, and Yucheng Shi. 2022. "Measurement and Analysis of Shock Wave Pressure in Moving Charge and Stationary Charge Explosions" *Sensors* 22, no. 17: 6582. https://doi.org/10.3390/s22176582

[5]: Nguyen, Hoang, Yosoon Choi, Xuan-Nam Bui, and Trung Nguyen-Thoi. 2020. "Predicting Blast-Induced Ground Vibration in Open-Pit Mines Using Vibration Sensors and Support Vector Regression-Based Optimization Algorithms" *Sensors* 20, no. 1: 132. https://doi.org/10.3390/s20010132

3. Operating Concept

3.1. Scope

The Portable High Energy Experiment Data Acquisition System (PHEE DAQ) will determine: (1) if an explosive event occurred, and (2) the general size of the explosive charge in pounds (lbs.) as a stretch goal. To accomplish this, various sensors will record an environment and send signals to a microcontroller which will condition and then process the signals in real time. The processed signals will then be analyzed based on an algorithm we will create and then the outputs of this algorithm will be stored locally on the DAQ along with the timestamp of the event. The local storage device will be removable so that the user can see the results.

3.2. Operational Description and Constraints

The PHEE DAQ will be used for explosives testing in controlled outdoor environments. The DAQ and its sensors will be placed in close proximity to an explosive charge where it will remain until after the explosive event occurs.

The PHEE DAQ has specific constraints specified by Sandia National Laboratories:

- It will be used in ideal environments where the only phenomenon that occurs is a single explosive event.
- The sensors on the DAQ will be at a maximum of 100 ft away from the explosive charge and at a minimum adjacent to the charge. In the case where the DAQ itself might be damaged by the explosive event, long wires will be used to connect the sensors to the DAQ which will be out of range of and protected from the blast.
- The processor on the DAQ should be capable of sampling at a rate of 2 kHz or higher.
- The processor on the DAQ also must be able to classify if an event is explosive in real time.
- A signal conditioner must be integrated into the design.

3.3. System Description

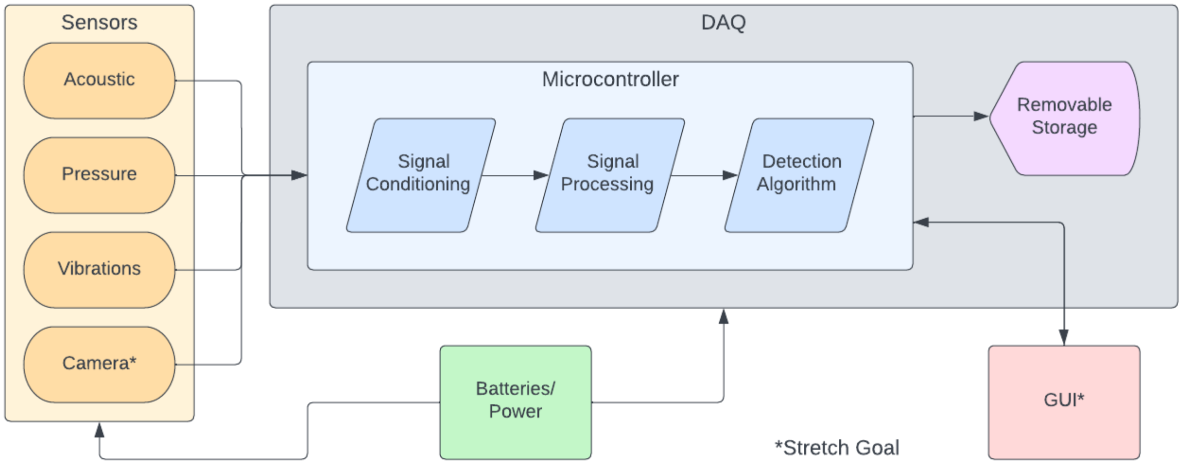

Figure 1: PHEE DAQ Block Diagram

The PHEE DAQ will consist of sensors, a microcontroller, and a removable storage device all integrated on a custom PCB which will be powered by batteries through a power supply. A GUI that can be used to visualize data from and change settings on the DAQ may be added to the system if time and resources permit. The system will be broken down into three general subsystems: (1) power, (2) software, and (3) hardware. Power includes designing the power PCB, hardware includes programming the microcontroller and designing the main PCB, and software includes writing code to process signals, detect an explosive event, and store the data. These subsystems can be broken down further into their specific components:

Sensors: Data will be acquired by our system through sensors that will measure the following:

- **Acoustic:** We will use a microphone that can pick up high-amplitude sound adequately to record the sound of the blast. Frequency will be important in determining if an explosive event occurred, but amplitude will be a more valuable metric considering how loud explosions are compared to other phenomena.
- **Pressure:** We will use either a diffusion silicon pressure sensor or a ceramic pressure sensor to measure the pressure of the air from the blast and shock waves due to the explosion. The blast wave produced from explosions, which consists of highly pressurized air, is a defining characteristic of explosions. We will use the pressure sensor to measure the high pressure from the shock front of the blast wave and the dynamic pressure of the air behind the shock front.
- **Vibrations:** We will use either an inertial measurement unit (IMU) or an accelerometer to measure vibrations from the blast wave. This sensor will be able to gather data on the force due to the high pressure of the shock front.
- **Camera:** A stretch goal may be using a camera to record video of the explosive event and using computer vision to analyze the light emitted from the explosion.

Signal Conditioning/Processing and Detection Algorithm: The data acquired through our sensors will then be sent to a microcontroller where we will use digital signal conditioning to enhance the signals by amplifying and filtering them. Then we will use digital signal processing to extract useful information from the signals to make them easier to analyze. Once our signals are in a format that is easy to understand, we will develop an algorithm that will analyze each metric in relation to time and decide if an explosive event occurred at that specific time.

Microcontroller: The microcontroller will be the brain of the entire system. We will program it to interact with the sensors, removable storage, and possibly the GUI. All our signal conditioning/processing and detection algorithm code will be run on this microcontroller and will be sent to the removable storage device and possibly the GUI. The removable storage device we will use is an SD card, so an SD card reader will be integrated into the circuit so that data can be written to it from the microcontroller.

Custom PCB: One option is that there will be a main PCB interfacing the microcontroller, sensors, and removable storage device reader and then another PCB for the power supply, power management. The other option is that there will be one PCB where all the previously mentioned components will be integrated together.

Power: To power the PHEE DAQ, we will design a PCB that will enable battery charging and distribute the power from that battery to the microcontroller and sensors that need power. This will require voltage level regulation, load management, and adjusting the charging rate of the batteries.

GUI: The GUI will display data received from the microcontroller onto a smartphone or laptop. This data will be in the form of waveforms or a summary of the data so the user can develop a general understanding of the data that has been gathered over a period of time. The GUI will also allow the user to configure settings to change how the data is sampled.

3.4. Modes of Operations

The default mode of operation for the PHEE DAQ will require that the DAQ is turned on by the user and placed in a suitable location relative to the explosive charge. The DAQ will run automatically without further interaction from the user until the user decides to remove the storage device.

The second mode of operation is a stretch goal for this project. This mode would include a GUI to allow the user to: (1) configure the necessary number of channels for optimum data sampling, and (2) select different channels to display a small sample of the data (e.g., a waveform or summary of data such as maximum, minimum, and average data points).

3.5. Users

The target users of our system are researchers and engineers from government agencies, industry, and academic institutions with focuses on explosives testing and defense technology. Because the target users of our system have all the following knowledge and training, we expect our target users to have very few problems with setting up and operating our system given a user manual:

- Users of our system should have previous knowledge of how DAQs work, but our system will be simple to set up and activate with minimal technical training.
- If the GUI is implemented, the user is expected to have knowledge of high shock and explosive events so that they can adjust the DAQ's settings accordingly.

3.6. Support

A user manual will be created to specify how to operate the PHEE DAQ. It will include how to set up the DAQ and its sensors, gather data from the storage device, and interact with the GUI. Any code written for the microcontroller will be commented and README files will be included in the repository to further explain the purpose of the code.

4. Scenario(s)

4.1. #1 Sensing Explosive Events for Defense Mechanisms

The portability of the high energy DAQ system enables its use in a wide variety of applications that require the sensing of events with extreme decibel levels, vibrations, and overpressure. This includes its use as a part of military defense systems that require the sensing and detection of explosive events. In addition to the DAQ system's portability, its rapid sampling rate of real-time data makes it useful for systems that require immediate action to be taken based on the event that is sensed. More specifically, it can be used as a part of a larger system that will deploy defensive mechanisms to protect equipment or personnel from the onset damage of an explosion in the event that one had been detected.

#2 Characterization of Explosive Event (Stretch Goal)

The high energy DAQ system's number and variety of data inputs enable it to not only detect the occurrence of an explosive event, but also characterize such an event based on the estimated size of the charge. The system will be able to compare the gathered data and differentiate explosive events on the order of a few grams to tens of pounds. This data can also potentially be used to analyze the different metrics to aid in explosive weapons research. The acoustics data gathered by the system can also be valuable in research related to any type of extreme decibel-level event such as ballistics or natural disasters.

5. Analysis

5.1. Summary of Proposed Improvements

The list of improvements that the high energy DAQ system offers includes the following:

- The system will be portable and self-powered allowing it to be used in any environment without danger to the user in the context of explosive event detection.
- The sensing devices will be multi-directional allowing it detect events of interest in a wide area and without line-of-sight of the event occurring.
- With on-board memory the DAQ system will be able to store its decision regarding a detected event of interest and the time associated with it, giving the user the ability to access the recorded data at any time.
- The DAQ system will feature highly durable temperature and shock resistant sensing devices that can withstand explosions directly adjacent to them.
- The wide variety of data gathered by the system along with the on-board data and signal processing offers modularity for use in many other applications.
- As a part of the stretch goals for this design, the DAQ system will be able to not only make decisions on identifying events of interest but display data metrics on the event of interest in real-time.

5.2. Disadvantages and Limitations

The limitations associated with the high energy DAQ system includes the following:

- The design must include sensing devices that are separate from the processing unit since the processing unit vulnerable to damage, limiting the compactness of the system.
- The sensing devices being separated from the processing unit also requires the use of long cables which are vulnerable to damage and contaminating the data with noise.
- The system's accuracy in sensing and identifying events of interest is reliant on certain explosive metric thresholds derived from previously recorded data of explosions. This may leave the system vulnerable to mis-identifying explosive events.
- To ensure data is acquired accurately, a mount will be designed to hold the sensors steady and position them correctly relative to the explosive event. As a result, the system is vulnerable to bad readings if the sensors are not mounted properly.

5.3. Alternatives

Several alternatives to the high energy DAQ system include the following:

- Use security cameras with computer vision to decide if an explosive event has occurred.
- Thermal imaging could be used to detect significant changes in temperature to identify explosions within a certain environment.
- A break trigger could be placed adjacent to an explosive charge so that an explosive event can be detected when the electrical signal through the trigger is interrupted.

5.4. Impact

Data-driven systems are in the forefront of technology within the present decade and the high energy DAQ system is among them and has potential to have significant impact in life-threatening situations. Because the system is designed for the detection and characterization of explosives it naturally entails a list of safety, ethical, and national security concerns. As mentioned earlier, its suitability to military defense systems designates it a technology that would be in the best interest of national security to prevent other nations or foreign threats to gain access to. Additionally, the DAQ system gathers data that is useful for research in explosives and ballistics testing. Because of the dangerous nature of this type of research there are safety concerns that must be considered when using this system. Users must be properly trained on the optimal safety conditions when using this system for sensing explosives or any type of high energy event. Further, the damage caused by explosive testing can be harmful to the environment if not properly contained.