UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

CAPSTONE Group 062 Bird Impact Detection System Design Document

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Executive Summary

The Bird Impact Monitor is a project inspired by SEEDS and their initiative on creating bird-friendly technology. UBC happens to be on the migrating path for many bird species and birds have important roles in the ecosystem. Previously studies commissioned by SEEDs estimated that over 10,000 die due to window collision on campus. The purpose of this project is to collect real-time bird impact data to help SEEDs implement a bird-friendly building guideline and for researchers to better understand birds' behavior.

Our goal is be replace the manual data collection done by SEEDS in previous years with an automated system that is able to detect bird impacts more accurately and with minimal maintenance. More detailed outlines can be found the the Requirements document.

The device is made of two sections: the detection system and the communication system. The detection system consists of an accelerometer connected to an Arduino Uno Wifi Rev 2. The accelerometer will be installed on the windows and transmits analog data to the Arduino for analysis and identification. Once

an impact is identified, the Arduino will send data to MyDevices Cayenne over Wifi. The client will be able to access and visualize the data using Cayenne.

The prototype we have developed is able to satisfy all of SEEDs requirements, in particular, it accurately detects bird impact with a 95% accuracy while rejecting environmental disturbances, it costs less than $80 per unit, and obstructs less than 10% of the window. Further recommendations to the project are outlined in the design documents and will serve as guidelines for future projects for improvements and scalability.

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FR1 Design Document Functional Requirement 1. Pages:. 30, 31, 36, 119

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List of Key Terms

Aliasing: Misidentification of the frequency of a signal. Causes distortion or error.

Analog Data: For a signal that is continuous, its time-varying feature is represented with another time-varying quantity.

Bird Impact: The event where a bird collides with the window upon which the Bird Impact Detection system is installed.

Database: A set of data that is held in a structured way in a computer.

Data Segment: A piece of a data packet containing certain information for storage. Includes timestamps and location data.

Kinglet: A type of bird identified by the client as being of high concern for bird impacts on UBC Campus.

Microcontroller: A computer that is composed on an integrated circuit, that has various distinguishable features (number of CPUs, memory, input/output peripherals).

Mock Bird: An object we use in order to simulate the equivalent energy produced by a bird, i.e., a kinglet.

Nyquist Frequency: Twice the maximum expected frequency of a signal, the minimum rate at which the signal may be sampled without introducing error.

SEEDS: The UBC Social Ecological Environmental Development Studies program.

Sensor: A device that can detect or measure physical properties.

User Interface: The method in which an user and a computer system interact.

Voltage: A potential difference with the unit of Volts.

1 System Architecture

The design for the product is divided into four major components:

- Detection System
- Communication System
- Data Storage
- User Interface (UI)

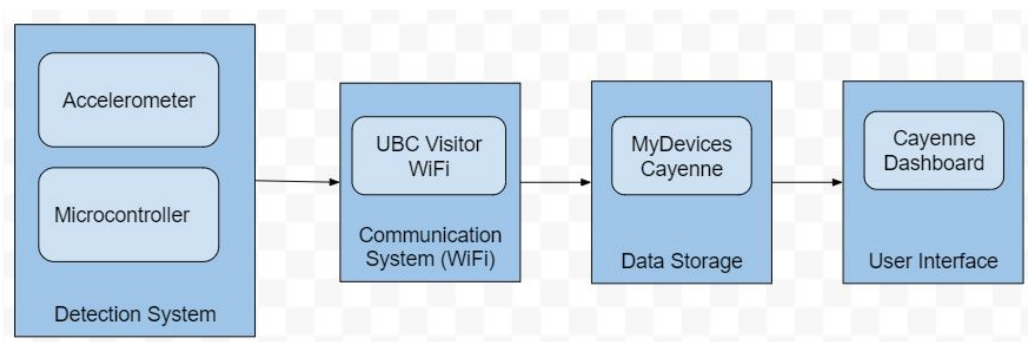

Figure 1: High-Level Design of the System

The detection system refers to an accelerometer and microcontroller device that will be attached to the window being measured (Section 3). The detection system in the system architecture is seen in Figure 1. The purpose of the detection system portion of the device is to monitor the window for any sufficient signal that represents a bird colliding with the glass. The detection system then sends this data to the data storage device for use and analysis by SEEDS.

The communication system (Section 4) refers to the WiFi connection the detection system uses to communicate data to data storage (Section 5). This subsystem ensures that all bird impact data recorded by the detection system is accurately transmitted to data storage. The primary purpose of the communication system is to make access of data more convenient by making it remotely accessible.

Data storage refers to Cayenne, which the detection system sends bird impact information to (Section 5). The purpose of the data storage portion of the device is to store impacts that are detected by the detection system. The data storage component provides a remote database that expands upon the space available for storage of impact data. As well, the data storage makes the impact data consistently available for the UI and access by SEEDS.

UI refers to the Cayenne Dashboard, which is used to present the data stored in the data storage component to users of the system (Section 8). It processes the data in data storage and presents it in an easily readable and user-friendly format. This includes a numerical counter that presents the location the data was collected, and a tally of total impacts at that location. In addition, the UI plots the data over time from the location associated with the counter.

1.1 System Operation

The system is designed to detect bird impact events that occur on the window the system is installed upon. An occurrence of a bird impact is defined as the primary condition in which the system will perform functions. The system does not perform functions outside of monitoring for the occurrence of a bird impact event. Figure 2 displays the path of data from a bird impact through the system.

The impact sensors continuously transmit data to the microcontroller representing the vibrations in the inner pane of the window the system is installed on. When a bird impacts the window the system is mounted on, the vibration generated is converted into analog signals by the impact sensors (Section 3.1). These analog signals are then transmitted as voltage along

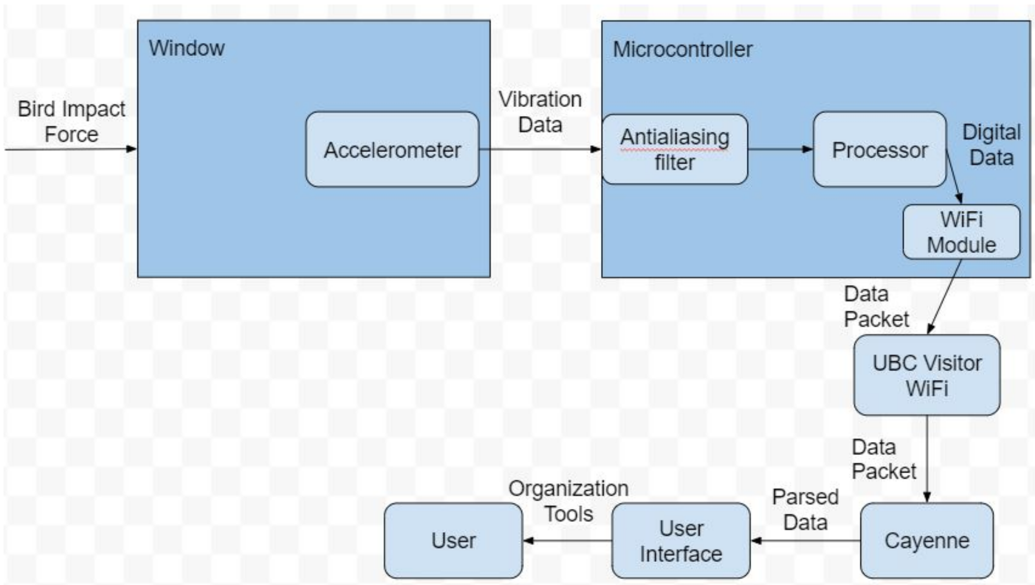

Figure 2: System Operation Data Pathway through System

wires to the microcontroller (Section 3.3) for processing.

Analog data is received by the microcontroller through wires that connect it to the impact sensors. The microcontroller then processes these analog signals, and monitors said signals for signs of a bird impact. When an impact is detected, the microcontroller records the event. Recording consists of creating an object in the microcontroller's memory, including the location and time of the impact. Location is defined as an identifier of which window the system is installed on, consisting of the building and an index referring to the window. Appendix A displays examples of locations recorded, in the column marked 'facade'. A digital record of the impact is then transmitted using the communication system (Section 4) to data storage (Section 5). An acknowledgement of the impact event is sent to the appropriate Cayenne channel. The Cayenne channel designates at which building location the system is located, and is coded into the Arduino.

The digital record packets sent by the microcontroller via WiFi are then received by Cayenne. Figure 3 displays how data is stored in Cayenne when a bird impact is received. Each line represents one data package that was received from the device by Cayenne. Sensor name is used to identify the location of the system, and is associated with the channel. Value refers to the number of impacts total that have been identified by the system since it was last reset. Timestamp is the approximate time when that data package was received, indicating when the associated impact occurred.

2 Simulation of Bird Impact

In a literature review, no previous work regarding the repeatable recreation of a bird impact was found. Due to this, a method for simulating an bird impact is created for use in designing and testing the Bird Impact Detection system. The client identified

Timestamp	Device Name	Channel	Sensor Name	Sensor ID	Data Type	Unit	Values
2019-01-28 7:06:42	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			17
2019-01-28 7:06:12	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			16
2019-01-28 7:05:42	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			15
2019-01-28 7:05:12	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			14
2019-01-28 7:04:42	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			13
2019-01-28 7:04:13	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			12
2019-01-28 7:03:43	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			11
2019-01-28 7:03:13	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			10
2019-01-28 7:02:43	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			9
2019-01-28 7:02:13	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			8
2019-01-28 7:01:43	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			7
2019-01-28 7:01:13	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			6
2019-01-28 7:00:43	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			5
2019-01-28 7:00:14	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			4
2019-01-28 6:59:44	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			3
2019-01-28 6:59:14	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			2
2019-01-28 6:58:44	Arduino a321	0	Marine Drive 15	cb435160-233b-11e9-809d-0f8fe...			1

Figure 3: Cayenne Data Presentation with Sample Data

the kinglet(2) as a bird of particular concern for bird impacts on UBC campus. This species is therefore used as the focus of bird impact simulations used to design and test the system. Appendix B provides more details, including calculations, for the design of a bird impact simulation. The bird impact simulation described in this section is used for all of the applicable testing done for design and validation of the system.

2.1 Mock Bird

The bird considered in the design of the mock bird is the kinglet, a species identified by the client as the most common for bird impacts on the UBC campus(3). Kinglets have the following physical characteristics:

- 7g mass.
- 14-18cm wingspan.

- 8-11cm length from head to tail.
- Foraging speeds between 2.7m/s and 9.7m/s.

An 18g rubber ball and a 57g tennis ball are used as the mock birds to simulate bird impacts on the test window. Figure 4 displays the mock birds that were used for the simulations. The mock birds are designed using the following characteristics:

- Mass
- Physical size (wingspan, length from head to tail)
- Flight Speeds

The two mock birds are purposefully designed to have a mass of 18g and 57g. This is done to limit the drop speed and drop height required to simulate bird impacts, facilitating repeatable and safe testing. A pendulum (Appendix C) is the chosen method of simulating the bird impacts because of its ability to control impact locations and finely tune the impact speed. Since the maximum speed of the kinglet is too fast to be effectively simulated in a lab setting using the pendulum, ideal kinematics equations are used with the increased masses of the mock birds to reduce the speed of the simulated impacts (Appendix B). We can ensure that the mock bird impacts are consistent with true kinglet impacts by maintaining equivalent impact energies, as

(a) Photo of 18g Mock Bird Used for Validation Tests

(b) Photo of 57g Mock Bird Used for Validation Tests

Figure 4: Mock Birds For Validation Tests

presented in Appendix B. The shape of the mock birds is chosen to be a ball to ensure that simulated impacts are unaffected by the rotation or other positioning upon collision with the window. To simplify the simulation, the effects of air resistance and deformation of the ball are disregarded.

2.2 Pendulum Setup

To simulate varied bird impacts in a reliable and repeatable manner, a pendulum is used. By varying the drop angle of the mock bird (Section 2.1), the pendulum can simulate different bird impact speeds on different spots of the test window. Appendix C describes the pendulum setup used in more detail.

2.3 Ideal Environment Simulation

This section describes an experiment that was conducted to supplement the design of the detection algorithm (Section 3.2) of the detection system (Section 3). The complete ideal environment simulation experiment can be found in Appendix D.

The purpose of this experiment is to identify important characteristics (peak-to-peak voltage, duration, and frequencies) captured by the accelerometer (Section 3.1) during a bird-window collision in ideal conditions. These characteristics are used in the design of the detection algorithm that can distinguish bird-window collisions from other by/on window disturbances, meeting NFR1. A secondary purpose of this test is to determine the best sensor placement location for the system setup (Section 7). This experiment is designed to mimic the ideal conditions in which the system will operate at the UBC Vancouver campus, with no external sources of noise such as rain or wind.

2.3.1 Sampling rate

In order to calculate accurate frequency peaks when performing a Fast Fourier Transform(4) to the data, we must determine the frequency range of impact vibration on the glass. To do this, we initially sampled the signal at the maximum rate of serial data transmission, 4000Hz, and recorded data in real time while applying short time Fourier Transform to study their frequencies.(5).

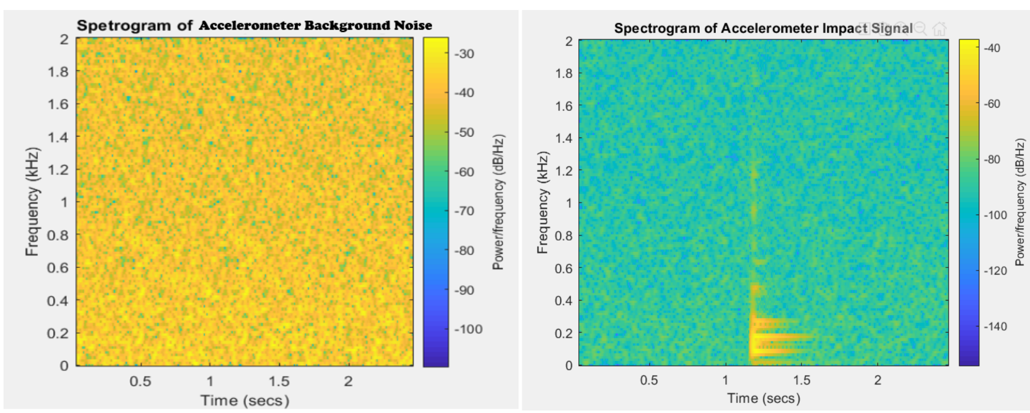

Figure 5: Accelerometer Signal Spectrogram of Ideal Environment Background Noise and Simulated bird Impact

Figure 5 shows the spectrograms of the ideal background noise (on the left), and a typical simulated bird impact (on the right).

It is apparent that the bird impact vibration is under 1000Hz. As a result, according to the Nyquist Frequency(6), the detection system is designed with a sampling rate of 2000Hz.

2.3.2 Results Summary

Testing multiple impact locations allows for the impact signal to be characterized. Impacts produce oscillating signals with an exponentially decreasing envelope in the time domain with two or four peaks at frequency domain.

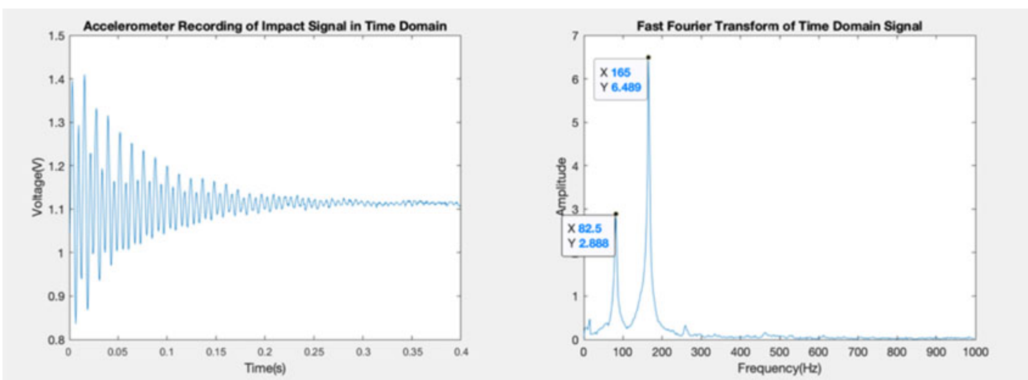

Figure 6: Best Case Accelerometer Impact Signal, Time Domain vs. Frequency Domain

Figure 6 shows the signals of the best case simulated impact, located on the center of a the glass. Appendix D, Figure D3 Location 6 displays an example of a best case simulated impact. This is a typical impact with two frequency peaks around 80Hz and 160Hz.

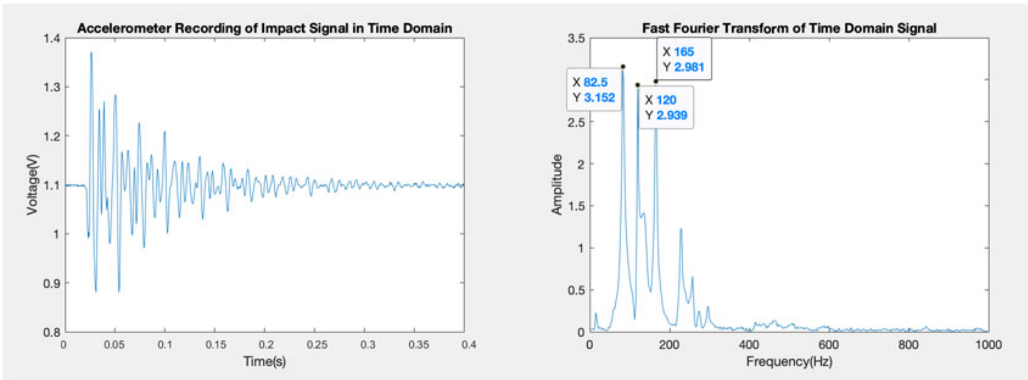

Figure 7: Worst Case Accelerometer Impact Signal, Time Domain vs. Frequency Domain

Figure 7 shows the signal of the worst case simulated impact, located near the edge of the window (refer to Appendix D: Figure D3: Location 1). This is not typical impact as it has four frequency peaks, which may be caused by the damping effect of the metal frame.

As shown by the best and worst case impacts, the signals have different maximum peak-to-peak voltages and frequency peaks.

2.4 Non-Ideal Environment Simulation

Similarly to Section 2.3, this section uses an experiment that was conducted to supplement the design of the detection algorithm (Section 3.2) of the detection system (Section 3). The complete non-ideal environment simulation experiment can be found in Appendix E.

The purpose of this experiment is to identify important characteristics (peak-to-peak voltage, duration, and frequencies) captured by the accelerometer (Section 3.1) during a bird-window collision with simulate environmental disturbances, rain and human sound. These characteristics are used in the design of the detection algorithm in order to distinguish bird-window collisions from other disturbances near the window, meeting NFR1. This experiment is designed to mimic the non-ideal conditions in which the system will operate at the UBC Vancouver campus, testing rainy and noisy conditions.

2.4.1 Results Summary

Based on the best and worst case impact data displayed in Appendix E, we can see that rain and noise increase the noise floor level, but it is significantly smaller than any bird impact signal and can therefore be ignored.

3 Detection System

The detection system consists of a microcontroller and one impact sensor. Figure 8 displays how these components are connected. The sensor used for impact detection is an accelerometer. This sensor is attached to the window being measured, in order to provide data to the microcontroller for processing. The microcontroller reads data from the sensor and uses it to determine whether a bird impact has occurred. If the microcontroller detects a bird impact, it sends an acknowledgement to the data storage (Section 5) using WiFi (Section 4).

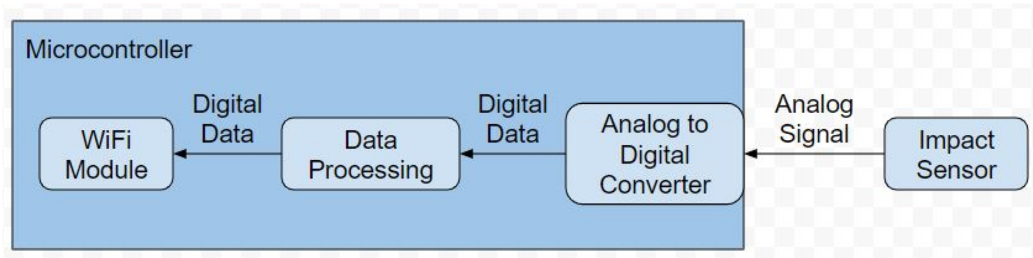

Figure 8: Detection System Diagram

3.1 Impact Sensor

A bird impact is made up of audible sounds, vibrations, and motion experienced by the glass of a window (7). The detection system uses an accelerometer to capture the information produced from audible sounds and window vibrations during an impact for bird impact detection (8). This sensor is used to meet FR1 and NFR1 of the system by accurately detecting bird impacts.

3.1.1 Accelerometer

The accelerometer ADXL337 is the impact sensor chosen for this project. Accelerometers are a type of sensor that outputs a voltage signal as a function of the force on the sensor in a specified direction. The accelerometer's versatile applications in building and structural monitoring make it applicable in our project(9). A kinglet, the bird identified by the client as being of most concern for bird impacts on UBC Campus, is estimated to produce approximately 0.2N to 3N of force which is equivalent to 0.026g to 0.33g upon impact as shown in the calculations in Appendix B(10).

In order to meet the cost constraint defined in C1, the accelerometer must also cost less than $30. In addition, a high sensitivity allows for the voltage output to be relatively large even when the vibration is small as in the case of a low speed impact. Since there is a trade-off between the sensitivity and the threshold of acceleration of an accelerometer, we decided to purchase an accelerometer with high sensitivity up to 330mV/g so that impact from a small bird flying at low speed can be detected to satisfy FR1 and NFR1. The sensor must have and operating temperature range of at least -10°C to 30°C. This is to ensure that the system will function inside of buildings on UBC Campus. This range sufficiently larger than the expected range of temperatures inside of buildingsto ensure the system will function properly. Given the above considerations, the minimum specifications of the accelerometer are summarized in Table 1(11).

Table 1: Technical Specifications of ADXL337

Feature	**Minimum Specification**	**ADXL337**
Input	0.026g to 0.33g	±3 to ±3.6g
Sensitivity	100mV/g	270 to 330mV/g
Operating Voltage Range	3.3 to 5V	1.8 to 3.6V
Operating Temperature	-10 to $30°C$	-55 to $+125°C$
Cost per Unit	less than $30	$16

3.1.2 Anti-aliasing Filter

Aliasing is a concern that arises in reading the analog signal from the accelerometer. The Nyquist Frequency of the system is approximately 520Hz, based on the bird impact simulation (Section 2). The Nyquist Frequency is calculated using the highest frequencies observed in simulation, approximately 260Hz. The system is sampling at 2000Hz, which is well above the minimum requirement and results in oversampling. This oversampling introduces high frequency white noise that may make the detection system less accurate. A physical anti-aliasing filter is used to reduce this effect.

This filter is implemented by connecting a capacitor between the z-axis output of the accelerometer and ground. As suggested by the manufacturer of the ADXL337 (Section 3.1.1), a 10nF capacitor is used(11). Figure 9 displays a sample bird impact signal without the filter implemented, and Figure 10 displays the same signal after the filter is implemented. The filter is implemented mathematically in these two figures, to highlight the effect of the anti-aliasing filter on a specific impact.

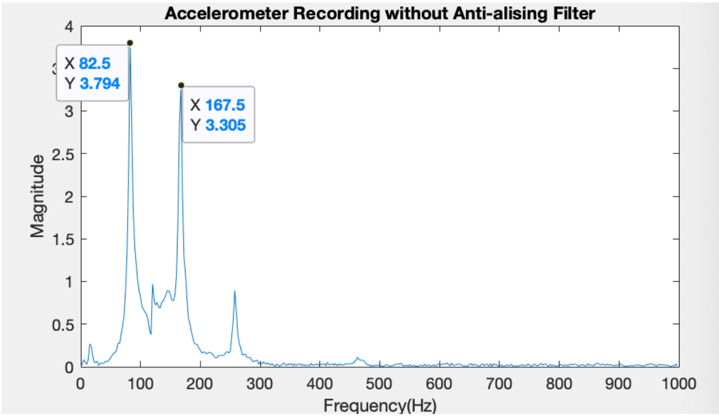

Figure 9: Sample Bird Impact Signal Before Anti-aliasing Filter is Applied

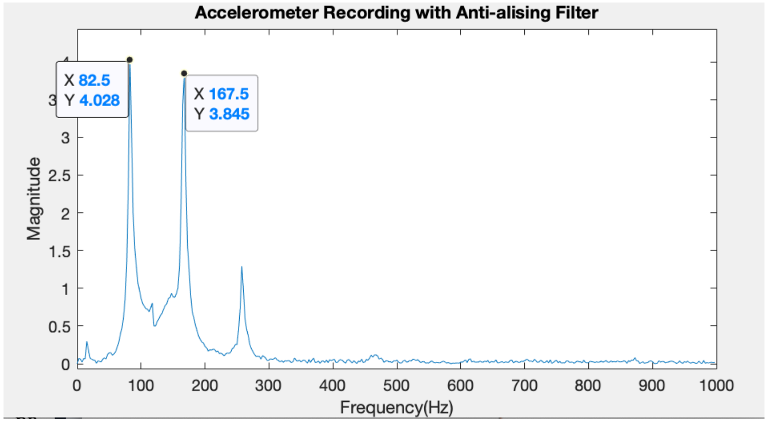

Figure 10: Sample Bird Impact Signal After Anti-aliasing Filter is Applied

The filter attenuates the signals used to identify bird impacts by up to 0.5dB, but maintains a satisfactory signal-to-noise ratio. In addition it significantly attenuates high frequency peaks, visible in frequencies above the peak at approximately 250Hz. This indicates that the filter is limiting the analog signal to within the frequencies that are expected in the event of a bird impact.

3.1.3 Other Sensors Evaluated

In addition to the accelerometer mentioned above, we have also considered microphones, a piezo disc array, and infrared motion sensors as alternative options. Microphones meet the requirements of the impact detection sensor, and are therefore a viable sensor option of the system. A microphone is not included in the final design as no situation was discovered during validation tests where the microphone was able to detect a bird impact that the accelerometer could not. The microphone as an impact detection sensor is discusses in more detail in Appendix G. Piezo discs are a type of pressure transducer that generate voltages when they are being compressed. However, piezo discs generate AC voltage, which is incompatible with the input format of the microcontroller. Therefore this option has been eliminated.

Infrared sensors emit infrared radiation and detect the reflected radiation from an object to determine if there is movement in the sensing region (12). These sensors were initially considered as a way of confirming the presence of motion immediately in front of the window when vibrations have been detected by the other impact sensors. The two IR sensors that were tested were the IR proximity sensor and the short-range distance sensor. However, IR sensors require mounting on the outside of the window to provide effective information from bird impacts. These sensors were therefore eliminated following the decision to place the system on the inside of the window, explained in Appendix H.

3.2 Detection Algorithm

To accurately detect bird impacts among the other vibrations of the window, an algorithm is needed. This algorithm is implemented on the Arduino Uno WiFi Rev2 (Section 3.3). The three characteristics of the signal that are used by the algorithm are:

1. Signal Voltage Amplitude
2. Dominant Frequency Peaks
3. Signal Duration

Bird impacts have distinct characteristics that can be used to distinguish them from other disturbances that cause vibration in the window glass. The algorithm is implemented using a state machine and a Fast Fourier Transform function for the Arduino Uno WiFi Rev2.

3.2.1 State Machine System

The algorithm is implemented using 4 different states:

1. Initialization
2. Voltage Reading
3. Identification
4. Data Uploading

The state machine is implemented using the Arduin Uno WiFi Rev2 (Section 3.3) to collect and analyze data from the accelerometer (Section 3.1). Figure 11 shows the state diagram for the system, including how the states are connected and basic next state logic. The primary purpose of the state machine is to satisfy FR1, FR2, NFR1, and NFR2, allowing the system to monitor for impacts autonomously with a low error rate.

3.2.2 Initialization State

The first state of the state machine is initialization, which is entered when the system is reset or powered on. If the system enters this state from a spontaneous power loss, it recovers the

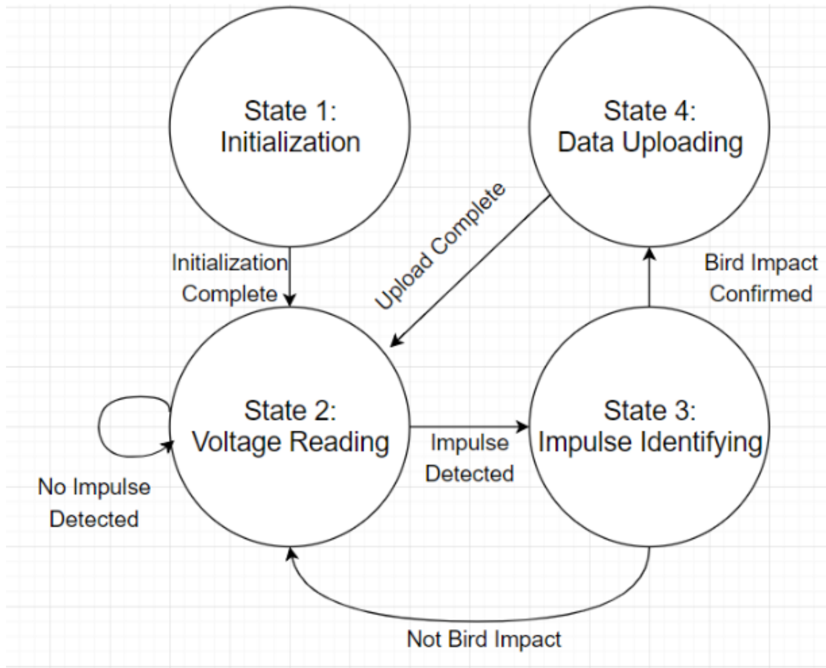

Figure 11: System State Machine Diagram

previous impact data from internal memory using a methodology defined below (Section 3.2.2.1). The system connects to the WiFi network (Section 4.3) and MyDevices Cayenne (Section 5). It then waits until the signal from the accelerometer becomes stable to avoid any issues with initial signal fluctuation. Once the system is connected to Cayenne and the signal is stable, it moves into state 2 (Section 3.2.3).

3.2.2.1 Recovery from Power Loss

Due to how bird impact information is stored on the Cayenne database (Section 5), the number of bird impacts recorded by the system must be recalled in the case of a loss of power. A power loss will erase the volatile local system memory, where the number of bird impacts is stored. Therefore, a method for recalling the bird impacts from a non-volatile memory is needed. This recovery from power loss occurs during the initialization state of the state machine, which is always triggered upon booting the device. The two types of system power loss are:

1. Power Supply Resets: power outage, a brownout, unplugging the power source from the system
2. User Resets: pressing the reset button on the device

To recognize a power loss, the algorithm makes use of a feature on the microcontroller (Section 3.3) called the Reset Controller; the source of a reset occurrence is recorded into the Reset Flag Register, shown on Figure 12 (1).
Each bit is binary, storing a value of 1 or 0. The bits of interest are:

Reset Flag Register

All flags are cleared by writing a '1' to them. They are also cleared by a Power-On Reset, with the exception of the Power-On Reset Flag (PORF).

Bit	7	6	5	4	3	2	1	0
			UPDIRF	SWRF	WDRF	EXTRF	BORF	PORF
Access			R/W	R/W	R/W	R/W	R/W	R/W
Reset			x	x	x	x	x	x

Figure 12: Reset Flag Register Bits (1)

- Bit 0: PORF - Power-On Reset Flag
- Bit 1: BORF - Brownout Reset Flag
- Bit 2: EXTRF - External Reset Flag

Bits 0 and 1 are set to 1 if a power supply reset occurs, while bit 2 is set to 1 if a User Reset occurs.
In the event of a power supply reset, the bird impact data is recalled from the non-volatile memory on the microcontroller. In the event of a user reset, the bird impact data is set to 0. This is expressed in the flowchart in Figure 13. This functionality was shown to work throughout various other tests, and is therefore validated.

3.2.3 Voltage Reading State

In this state, the system continuously monitors the signal from the accelerometer for the amplitude characteristic of a bird impact. The previous 25 milliseconds of accelerometer signal are

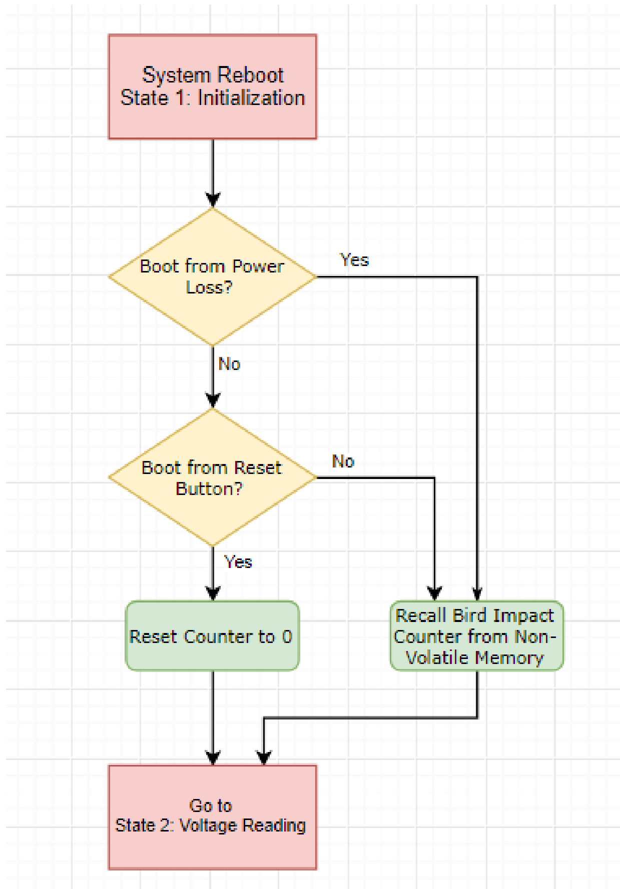

Figure 13: Recovery from Power Loss Flowchart

stored. When the signal amplitude becomes larger than the threshold of 0.0968V (ten times of ideal environment noise floor), the system moves into state 3 (Section 3.2.4). Additionally, an LED attached to the microcontroller indicates when the system is in this state to confirm the system is working properly. The LED is on when in this state, and turns off when in any other state.

3.2.4 Identification State

In this state, the system analyzes the data recorded from the accelerometer for signs of a bird impact. The three key characteristics of amplitude, frequency peaks, and signal duration are analyzed (details of these calculations can be found in Appendix F). Upon entering this state, an additional 400 milliseconds of signal from the accelerometer are stored. A Fast Fourier Transform allows the Arduino Uno WiFi Rev2 to identify the frequency peaks of the signal, and the signal duration may be calculated. The frequency peaks that the system monitors for are:

1. 80Hz
2. 120Hz
3. 160Hz
4. 170Hz

If the duration of the signal is within the window of 0.1-0.3 seconds and the dominant frequency peaks match the characteristic peaks, the system moves into state 4 (Section 3.2.5). Otherwise, once analysis is complete the system moves back into state 2 (Section 3.2.3). Figure 14 displays the flowchart for this process of analyzing the signal.

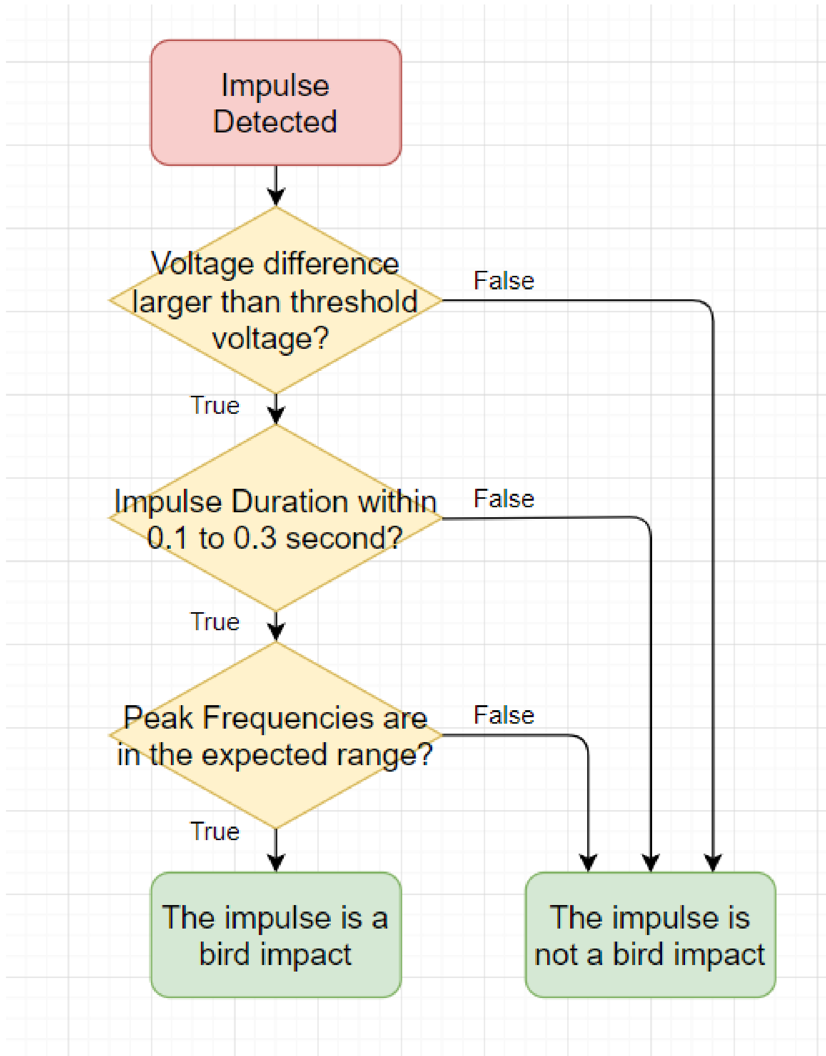

Figure 14: Flowchart of the Detection Algorithm

3.2.5 Data uploading

If the system identifies window vibrations as a bird impact, it enters this state. The system updates the online data storage (Section 5) with the new bird impact using WiFi (Section 4) and saves the bird impact data for recovery (Section 3.2.2.1). Once the system confirms that the data packet has been sent, it automatically goes back to state 2 to continue monitoring for impacts (Section 3.2.3).

3.3 Microcontroller

The microcontroller chosen for the system is the Arduino Uno WiFi Rev2(13). Table 2 compares the specifications of this microcontroller to the minimum specifications. The Arduino Uno WiFi Rev2 meets or exceeds the minimum microcontroller specifications.

3.3.1 Microcontroller Design Considerations

The following design components are considered in the microcontroller choice:

1. Microcontroller code size of 15kB
2. 100B data packets
3. Maximum of 48 bird impact events per day
4. 33.6kB of potential stored data per 7 day period

The code size consideration is based on the size of the code that is developed for the microcontroller to perform the signal processing (Section 3.2). The code requires up to 11kB of flash memory for the microcontroller to analyze impacts. 15kB is chosen as the design parameter to account for future additions to the code, as well as associated libraries required for function.

The 100B data packets and 48 bird impact events per day is based on the data provided by the client, included in Appendix A. The size of 100B was found by saving a sample max-size characteristic data packet received from the detection system as a text file. The size of this file was significantly under 100B, but the minimum specification was chosen to be over-designed in case more information is required in data packets in the future. 48 events per day is decided by analyzing the data provided in Appendix A for the maximum annual collisions on any given window on UBC Campus. The max number of impacts on one window per year previously found by the client is 26. This design consideration is overestimated in case the client data is low compared to the actual number of bird impact events is underestimated, or if the system is used in an area that experiences more bird impacts in the future.

The maximum potential stored data per 7 day period is decided by items 2 and 3 above. This consideration only considers the worst-case scenario where the system is unable to connect to the network for the entire 7 day period due to unexpected circumstances. 48 100B data packets is used to find that up to 4800B of data packets may need to be stored locally on the device in this scenario. For the entire 7 day period before maintenance, this indicates up to 33600B of data may need to be stored, or 33.6kB.

3.3.2 Minimum Specification Description

The impact sensor (Section 3.1) consists of a single accelerometer. To support the Detection System, the microcontroller must have one analog input pin for each of the two sensors. The accelerometer requires a 3.3V output pin that provides at least 300μA of current(11). The sensor sampling rate must be at least 520Hz, the Nyquist frequency for simulated bird impact events. The minimum clock speed of the microcontroller must be at least this value to ensure sensor signals on the event of a bird impact may be read properly. The microcontroller must also have at least 15kB of flash memory to hold code for sensor analog-to-digital conversion (Section 3.2). To fulfill NFR2, the microcontroller must have 33.6kB of on-board memory for backup storage. This considers the case where the microcontroller is unable to send data using the UBC Visitor network (Section 4) upon detecting a bird impact. It assumes impact data packets of approximately 100B, with 48 events stored per day for the entirety of the maintenance period of 7 days. To satisfy FR3 the microcontroller choice must be able to communicate wirelessly using WiFi (Section 4).

Table 2: Microcontroller Minimum Specifications

Feature	**Minimum Specification**	**Arduino Uno WiFi Rev2**
Analog Pins	1	6
Output Voltage	3.3V	3.3V
Output Current	300μA	50mA
Clock Speed	520Hz	16MHz
Flash Memory	15kB	48kB
Memory Storage	33.6kB	6,144kB
Onboard WiFi Module	Yes	Yes

See Appendix I for other microcontrollers evaluated.

3.4 Recommendations for Future Components

Four components were conceptualized for the detection system that are not included in the final design. These components could all be included in future iterations of the detection system to potentially increase its functionality. The components conceptualized that are not included are as follows:

1. Digital filter for the accelerometer (Section 3.1.1)
2. Microphone sensor for impact detection
3. WiFi disconnection in the case of long-term loss of network
4. Damping Ratio Analysis for Detection Algorithm

These components are presented in Appendix G. Due to the varying stages of development of each component before they were removed from consideration for the final design, they are not presented in a completed format. These are suggestions for future design components that would potentially be beneficial for the system.

4 Communication System

The data communication method chosen for the system is WiFi(14). The WiFi network that is used on UBC Campus is UBC Visitor(15) (Section 4.2). Table 3 compares the specifications of WiFi to the minimum specifications for the subsystem. WiFi meets the minimum data communication specifications, so it is chosen for the system.

4.1 Communication System Design Considerations

The main design consideration for the communication system is the transmission rate of 4B/s. This assumes characteristic

Table 3: Data Communication Minimum Specifications

Feature	Minimum Specification	WiFi
Wireless	Yes	Yes
Connectivity	Across UBC Campus	Across UBC Campus
Transmission Rate	4B/s	737500B/s

data packets of 100B (Section 3.3.1) being transmitted by the detection system (Section 3). In addition, this consideration assumes a 30 second limit on transmission of data communication from the detection system to data storage. This limit is derived from what is perceived as a reasonable amount of time for data packets to be available after a bird impact event occurs.

4.2 Minimum Wireless Specifications Description

The Detection System (Section 3) must be able to communicate with Data Storage (Section 5) wirelessly to satisfy FR2, FR3, and NFR3. Wireless communication removes the need for the user to gather data from the device manually, so access is easier. Wireless communication also ensures impact data is continuously available from the system data storage. Connectivity is defined as a minimum specification instead of range due to the availability of WiFi throughout UBC Campus(16). To ensure that the system can meet C5, the communication system must be able to connect across UBC Campus. The data transmission rate must be at least 4B/s (Section 4.1).

4.3 UBC Visitor WiFi Description

The UBC Visitor WiFi network(15) is a low-bandwidth network provided for guests of UBC Campus that are not faculty or students. It is an unsecured network that only requires accepting a terms of service to access. UBC Visitor is used instead of UBC Secure(17) due to the Arduino Uno Wifi Rev2 (Section 3.3) being unable to validate with the UBC Secure network's security protocols. Due to the relatively low bandwidth required for the communications, the limits of the UBC Visitor network are not a concern for the function of the system.

4.4 Accessing the UBC Visitor Network

Under normal circumstances, microcontrollers and similar devices are unable to access the UBC Visitor WiFi network(15). To connect to the network, the MAC address of the microcontroller used must be registered with UBC IT. This service is offered due to the low overall bandwidth of the system communication. In addition, it is important that the system microcontroller connects to the network at least once per week to ensure that the device stays registered on the UBC Visitor WiFi. This is considered to meet NFR2, as this maintenance is required only once in every 7 day period.

4.5 Other Data Communication Designs Evaluated

Other options that were evaluated for wireless communication are:

- LoRa(18)
- Bluetooth 5.0(19)
- Zigbee(20)

Table 4: Communication System Evaluation

Feature	**WiFi**	**LoRa**	**Bluetooth 5.0**	**Zigbee**
Wireless	Yes	Yes	Yes	Yes
Connectivity	Across UBC Campus	Limited on UBC Campus	Requires new infrastructure	Requires new infrastructure
Transmission Rate	737500B/s	31.25B/s	250000B/s	31250B/s

Table 4 compares these options to WiFi communication. All of the options considered would meet the minimum specifications for the communication method. WiFi was chosen due to its convenience and existing availability on UBC Campus. In addition, WiFi has extensive support available online. Therefore, it is chosen as the communication system.

5 Data Storage

Data storage for the system uses MyDevices Cayenne(21). The Cayenne database presents data in a processed and accessible format. It is also used to facilitate the system UI (Section 8). If required, data may be downloaded directly from the Cayenne database in a spreadsheet format, which is the format provided by the client shown in Appendix A. Table 5 compares the specifications of Cayenne with the defined minimum specifications.

5.1 Data Storage Design Considerations

The following design components are considered in the data storage choice:

- Able to store 3 individual data segments per impact
- Data segment max size of at least 32 characters

The 3 data segment design consideration for data storage is based on the minimum required data specified by the client. It is required that the system store 3 different pieces of data on the event of a bird impact:

- Bird impact timestamp
- Bird impact location marker, identified as a specific window in a building
- Number of bird impacts at that location

This ensures that the system can store all of the data required by the client on the event of a bird impact.

The max data segment size of 32 characters is based on the sample data provided by the client in Appendix A. It is based on the window location identifiers, which have the longest data segments included in this sample data. 32 characters is over-designed based on the sample data provided, to provide flexibility in future location identifiers that may be used.

5.2 Minimum Specification Description

These specifications assume that the data packets stored are a maximum size of 100B, with 48 events per day for a 7 day maintenance period (Section 3.3.1). It is assumed that at the end of the 7 day maintenance period, a user ensures that the data storage subsystem has sufficient space remaining. Each package of event data consists of three segments - a timestamp and window identifier, to satisfy C2, and a total number of bird impacts at that location. To meet FR2, FR3, and NFR2, Cayenne must have at least 33.6kB of storage space (Section 3.3). In addition, data storage must be able to hold at least 1008 individual segments of data. This number ensures that the system may store 48 3-segment data packets per day, for 7 days as described above (Section 3.3.1, Section 5.1). To store the impact location data, each data segment should be capable of storing at least 32 characters (Section 5.1).

Table 5: Data Storage Minimum Specifications

Feature	**Minimum Specification**	**Cayenne**
Storage Size	33.6kB	Unlimited
Unique Data Segments	1008	Unlimited
Data Segment Length	32	Unlimited

5.3 Cayenne Database

The primary data storage method for the system is a Cayenne database(21), provided by MyDevices(22). Figure 3 shows how data is stored in the Cayenne database. Cayenne meets or exceeds all of the minimum specifications for data storage, so it provides a viable solution. Cayenne also provides tools for accessible displaying and accessing of data, used for the UI (Section 8). Cayenne services are also provided for free, making it a good choice for the system.

5.4 Other Data Storage Designs Evaluated

Other options that were evaluated for data storage are:

- Secure Digital (SD) Card(23)
- Amazon Web Servers(24)
- Dropbox(25)
- Google Sheets(26)

Table 6 compares Cayenne and Google Sheets to the three options that were not chosen. Google Sheets meets or exceeds all of the requirements for data storage, and was implemented in early iterations of the system. Due to issues encountered with reliability, it was removed from the final version of the system. More information regarding Google Sheets and why it was not implemented is presented in Appendix J.

The SD card was not chosen as it requires the data from the detection system be stored with the system, rather than online. This reduces accessibility, as the data must be collected manually from the SD card. An Amazon Web Server was not

Table 6: Data Storage Evaluation Comparison

Feature	**Cayenne**	**Google Sheets**	**SD Card**	**Amazon Web Servers**	**Dropbox**
Storage Size	Unlimited	Unlimited	512GB	5GB	2GB
Unique Data Segments	Unlimited	$5 * 10^6$	Unlimited	Unlimited	Unlimited
Data Segment Length	Unlimited	50,000	Unlimited	Unlimited	Unlimited

chosen due to Cayenne and Google Sheets providing sufficient services for free, while a S3 Web Server has a more limited free model(24). Dropbox was not chosen as it is limited to 2GB of free storage(25), while Cayenne and Google Sheets do not have a limit to future free scalability.

6 Power Source

The system is powered by a power adapter. Table 7 compares the specifications of an power adapter to the minimum specifications for the subsystem. The power adapter meets the minimum power specifications, so it is chosen for the system.

Table 7: Power Source Minimum Specifications

Feature	**Minimum Specifications**	**Power Adapter**
Power Capacity	2000 mAh	Unlimited
DC Output	Yes	Yes
Output Voltage	9-12 VDC	9-12 VDC
Output Current	250 mA	250 mA
2.1 mm Plug	Yes	Yes
Center Pin Positive	Yes	Yes
Obtrusiveness of Window	Less Than 10%	$< 1\%$

6.1 Minimum Specification Description

The method for powering the system must satisfy C3, and NFR2. The power source must also be compatible with the microcontroller (Section 3.3). The system in an idling state consumes 12 mAh of power, so the power source of the system must have a capacity of 2000 mAh at minimum. The power method must be compatible with a center 2.1 mm center positive plug, have a VDC output of 9-12 V and have an output current of 250 mA(13).

6.2 Other Power Options Evaluated

The other option evaluated for powering the system is by battery.
Table 8 compares a power adapter to a battery.

Table 8: Power Source Evaluation Comparison

Feature	**MAKITA BL1013 2000MAH 10,8V LI-ION** (27)	**Power Adapter**
Obtrusiveness of Less Than 10% of Window	Yes	Yes
Compatibility with Arduino	Yes	Yes
Maintenance Need	Yes	No

The microcontroller (Section 3.3) consumes a minimum of 12 mA at 5V and 16Hz while it is in an idling state since it has capacities of standard shield, a standard USB interface, power regulation and LEDs (13). A battery that met the minimum specifications in Table 8 was considered and is a viable option for powering the system. However, a power adapter is more reliable and convenient for the maintenance of the system.

7 System Setup

The physical portion of the Bird Impact Detection System consists of a microcontroller and sensor (Design Document Section 3) that are mounted on the indoor side of window being observed for bird impacts. The decision to place the system indoors is explained in further detail in Appendix H. The sensor for the detection system is connected to the microcontroller directly (Section 7.1). The sensor itself affixed to the indoor glass pane of the window directly, and the microcontroller is attached to the window frame in a plastic enclosure (Section 7.2). The physical components of the Bird Impact Detection System are linked to the non-physical components through a WiFi module in the microcontroller (Section 3.3)

The non-physical portion of the Bird Impact Detection system consists of a WiFi wireless internet connection (Section 4), MyDevices Cayenne (Section 5.1), and the UI (Section 8). MyDevices Cayenne is connected to the detection system through use of the internet (Section 6.3.1). The UI is connected to MyDevices Cayenne directly, as a provided service from MyDevices (Section 6.3.2).

7.1 Sensor Connections

The detection system sensor (Section 3.1) is connected to the microcontroller (Section 3.3) using solid-core insulated wires. Figure 15 displays the schematic for the wiring in the detection system. It is noted that the ADXL335 is displayed in the schematic, as the software used for the schematic labels all ADXL3XX accelerometers this way. In the construction of the system, the ADXL337 should be used, as specified in the Detection System (Section 3.1).

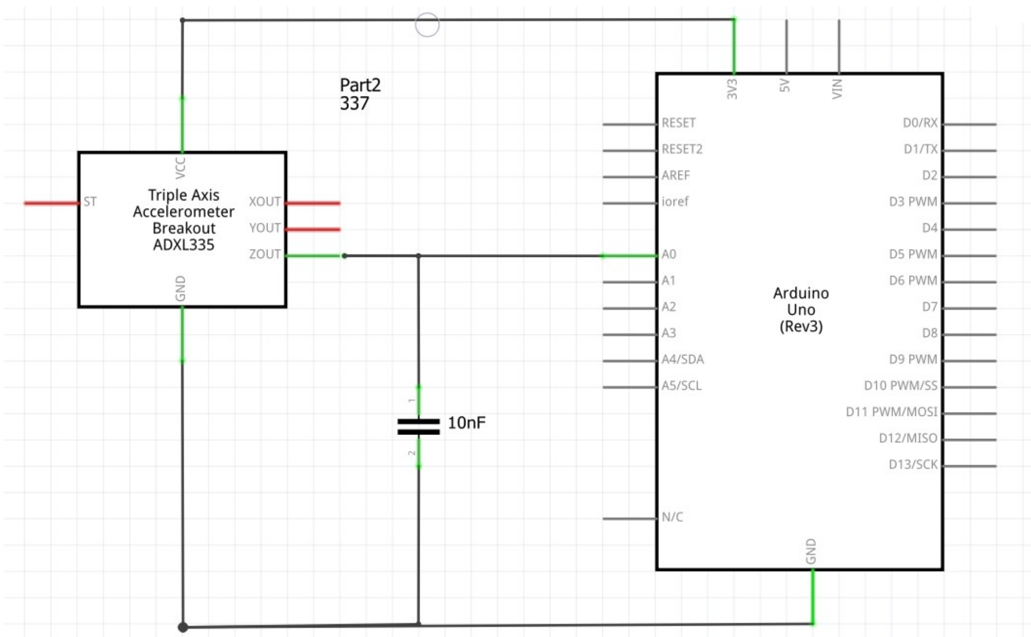

Figure 15: Detection System Wiring Schematic. It is noted that due to a limitation in the schematic generator, the ADXL335 is displayed instead of the ADXL337.

The pins of the sensors are connected to the microcontroller as follows:

1. Accelerometer Z-axis: Connected to input pin A0 of the Arduino Uno Wifi Rev2.
2. Accelerometer 3.3V: Connected to the 3.3V power pin of the Arduino Uno Wifi Rev2.
3. Accelerometer Ground: Connected to the ground pin of the Arduino Uno Wifi Rev2.

The Accelerometer X- and Y-axis pins are not connected to the microcontroller as they are not used in impact analysis (Section 3.2). A 10nF capacitor is attached between the accelerometer Z-axis and ground to filter the signal that is recorded by the Arduino Uno WiFi Rev2 (Section 3.1.2).

7.2 Detection System Window Installation

The detection system (Section 3) must be able to be attached in an operating position on the inside of a window to satisfy C4. The justification for why the system is installed on the inside rather than outside of a window is found in Appendix H. The installed system must be able to detect bird impacts to satisfy NFR1. The system consists of an accelerometer and a microcontroller as displayed in Figure 2, connected using wires.

A power adapter (Section 6) connects the Arduino Uno WiFi Rev2 (Section 3.3) to an appropriate wall plug for power. A waterproofing solution for potential future iterations is found in Appendix :, if the system is changed to outside installation.

7.2.1 Microcontroller Window Installation

The Arduino Uno Wifi Rev2 microcontroller (Section 3.3) is placed in a plastic enclosure box with dimensions of 7.62x7.62x3.81cm. The microcontroller is positioned on posts inside of the enclosure that keep it in place. Figure 16 displays the microcontroller installed inside the plastic box. A cover is normally included that encloses the microcontroller, but is not shown in the figure for visibility. Holes are included in the design of the box to allow sensor wires, computer cables, and power to be connected. In addition, a cavity is included in the box below the microcontroller to allow for the filter capacitor of the accelerometer to be installed (Section 3.1.2).

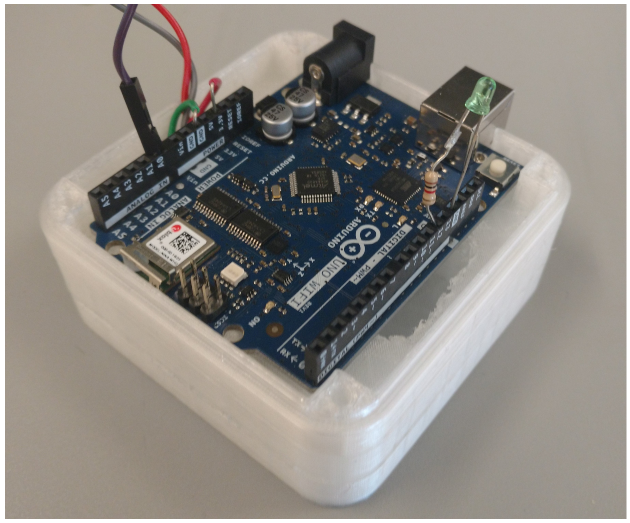

Figure 16: Microcontroller Installed in Plastic Box

This enclosure box is mounted on the metal frame of the window being measured using double-sided mounting tape.(28). The box is placed with one edge 10.795cm from the frame of the window and one edge directly against the window glass, with the serial and power ports facing away from the window glass. Figure 17 displays the plastic box affixed to the sample window, identified by the red circle.

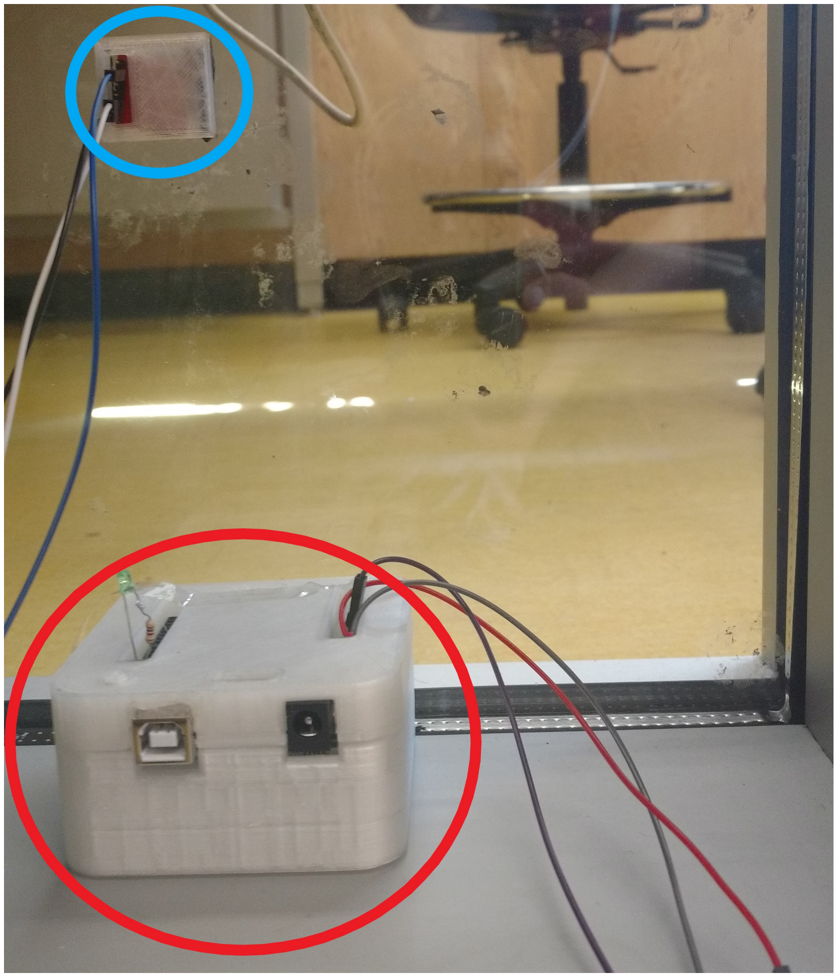

Figure 17: Microcontroller inside Plastic Box (Red Circle), Accelerometer with Cover (Blue Circle) Affixed to Sample Window

7.2.2 Sensors Window Installation

The accelerometer (Section 3.1) is affixed directly to the window using duct putty(29), under a 3.175x3.175cm square plastic cover. Duct putty is a secure adhesive that does not harden in most circumstances, while still transferring the majority of the vibration energy from the surface it is attached to. This makes it a good choice for the situation of the project, as it does not damage the window and allows for sensors to remain attached for long periods of time. An alternative that was considered was double sided tape. However, double sided tape dampens the vibrations transmitted to the sensor attached to the window due to thickness compared to duct putty. In addition, a plastic cover is attached over the accelerometer using duct putty to protect it and keep it secured. Figure 17 displays the accelerometer affixed to the sample window, identified by the blue circle.

7.2.3 Power Source Installation

The adapter described in Section 6 (Power Source) that powers the system is mounted against the wall beside a subject window. The adapter is mounted using cable tie mounts. These cable tie mounts will be installed using double-sided wall-safe tape(28).

7.3 MyDevices Cayenne Database Connection

Appendix K provides detailed instructions for setting up the MyDevices Cayenne database and connecting it to the Arduino Uno WiFi Rev2. The detection system (Section 3) is connected to the MyDevices Cayenne database (Section 5) using the communication system (Section 4). The microcontroller in the detection system communicates directly with Cayenne directly through the use of Cayenne libraries for the Arduino. No other setup is required for the detection system to communicate with Cayenne, as long as the communications system is accessible and the detection system is provided with the correct Cayenne credentials following the tutorial.

8 User Interface

The UI for the system is handled using MyDevices Cayenne(21). Table 9 compares the specifications of the Cayenne UI to the minimum specifications. MyDevices Cayenne exceeds the minimum UI specifications, so it is chosen for the system. In addition, Cayenne is used as the primary data storage (Section 5), so it is the primary choice for the system UI. Figure 18 displays how data is presented to the user in the Cayenne Dashboard. Window identifier refers to the building and window index that identifies which window the detection system is installed on. Number of impacts is the total impacts detected by the system since it was installed on the window being monitored, presented by the numerical counter. The line graph presents the impact data over time to highlight bird impact number trends. Additionally, Cayenne allows for data to be downloaded in a spreadsheet-ready format.

Table 9: UI Minimum Specifications

Feature	Minimum Specification	Cayenne
Data Visualization	Numerical Counter	Numerical Counter, Line Plot, Database, Spreadsheet Download

Figure 18: Cayenne Dashboard UI featuring numerical counter (left) and line plot (right) widgets, populated with sample data.

8.1 Minimum Specification Description

The UI must continuously provide a clear and easy-to-use visualization of data to satisfy FR3 and NFR2. Visualization of data refers to presenting data from the data storage (Section 5) in a user friendly manner. The UI must at least present a numerical counter of the number of impacts on the window the system is installed on.

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Appendix A: Client Sample Collected Data

facade	annual.collision		facade	annual.collision
Asian Centre 1	21		Marine drive 1	0.5
Asian Centre 2	2.5		Marine drive 10	1
Asian Centre 3	4.5		Marine drive 11	1.5
Asian Centre 4	7		Marine drive 12	2
FP 1	0		Marine drive 13	2.5
FP 2	0		Marine drive 14	0
FP 3	2.5		Marine drive 15	4
FP 4	1		Marine drive 2	2
FP 5	3.5		Marine drive 3	2.5
FP 6	0		Marine drive 4	5.5
FP 7	9		Marine drive 5	0
FP 8	0		Marine drive 6	3
International 1	16		Marine drive 7	0
International 2	0		Marine drive 8	0.5
International 3	0.5		Marine drive 9	0
International 4	0		Okanagan 1	1
Irving 1	2		Okanagan 2	6
Irving 10	19.5		Okanagan 3	0
Irving 2	2		Okanagan 4	3.5
Irving 3	0		Osborne 1	0
Irving 4	26		Osborne 2	2.5
Irving 5	1		Osborne 3	1.5
Irving 6	1.5		Osborne 4	4
Irving 7	1		Wesbrook 1	0
Irving 8	2		Wesbrook 2	0
Irving 9	1.5		Wesbrook 3	0.5
			Wesbrook 4	0
			Wesbrook 5	1.5
			Wesbrook 6	1
			Wesbrook 7	0
			Wesbrook 8	1.5
			Wesbrook 9	0.5

Appendix B: Bird Impact Calculations

The following details the process of representing a bird impact mathematically for the kinglet. Kinglets commonly have approximately the following relevant attributes:

- 10cm length from head to tail
- Mass of 7g
- Flight speeds between 2.7m/s and 9.8m/s

The mock bird is approximated using these properties (Section 2.1). The force imparted upon a window is then calculated using the following equation for force in units of g (gram-force):

$$F = \frac{mv^2}{2d} * 0.0098$$

The parameters are defined as follows:

d: The distance over which the bird impact is delivered, estimated as the 10cm length of the bird.

m: The mass of the average kinglet, 7 grams.

v: The speeds of impact considered, defined as the flight speeds above.

Table B1 displays the impact forces calculated using the equation above for the considered flight speeds of the kinglet.

Table B1: Energy transfer of 7g bird at bird-window collision.

Kinglet Impact Speed (m/s)	**Calculated Impact Force (gram-force)**
2.7	0.026
9.8	0.342

It is noted that for simplification, these estimated impact forces disregard parameters such as dampening due to feathers during the impact.

For testing purposes, the energy of the bird at the moment of collision will be considered instead of the impact force. Kinetic energy is used to represent a bird impact, and potential energy is used to simulate the impact using a pendulum (Section 2.2). This is due to the use of a physical approximation of the bird (Section 2.1) with significantly different physical properties from a bird in terms of shape, compressibility, and mass. The two equations used for calculation of kinetic (E_k) and potential (E_p) energies are:

$$E_k = \frac{1}{2}mv^2$$

$$E_p = mgh$$

The parameters used in these equations are defined as follows:

m: The mass of the kinglet (7g) or the mock bird (18g) (Section 2.1)

v: The velocity of the kinglet or mock bird. To cover a range of impact speeds, the following speeds are considered:

- 9.8 m/s (6.2 m/s)
- 6 m/s (3.83 m/s)
- 2.7 m/s (1.7 m/s)

g: The gravitational constant, approximated as 9.81 m/s^2

h: The drop height required to simulate a bird impact at the given speed

To simulate a bird impact, the kinetic energy of a kinglet at the desired impact speed is calculated. Table B2 displays the kinetic energies of the three impact speeds considered, which are defined above.

Table B2: Energy transfer of 7g bird at bird-window collision.

Speed Label	**Kinglet Speed (m/s)**	**Energy Transferred** E_k (J)	**Drop Height (m)**
High Speed	9.7	0.336	4.8
Medium Speed	6	0.126	1.8
Low Speed	2.7	0.0255	0.37

A pendulum (Section 2.2) is used to swing the mock bird (Section 2.1) at the window to simulate bird impacts. To approximate a real bird impact, the height required for the mock bird to be dropped from the pendulum is equated to the kinetic energy of the real impact. Tables B3 and B4 display the drop heights calculated for each required kinetic energy value defined in Table B2 for both mock bird masses. It is assumed that all of the potential energy is transferred into kinetic energy during the swing towards the glass of the window.

Table B3: Energy transfer of 18g mock bird at bird-window collision.

Speed Label	**Mock Bird Speed (m/s)**	**Potential Energy** E_p (J)	**Drop Height (m)**
High Speed	6.2	0.336	1.9
Medium Speed	3.83	0.1268	0.71
Low Speed	1.7	0.0255	0.14

Table B4: Energy transfer of 57g mock bird at bird-window collision.

Speed Label	**Mock Bird Speed (m/s)**	**Potential Energy** E_p (J)	**Drop Height (m)**
High Speed	3.43	0.336	0.60
Medium Speed	2.10	0.1268	0.22
Low Speed	0.94	0.0255	0.045

Appendix C: Simulation Pendulum Setup

To simulate bird impacts, a setup is required for impacting the mock bird on the window. This setup must be adjustable for both impact speed and location impacted on the window. The setup chosen is a pendulum design. Figure C1 displays the pendulum set up over the sample window in the manner used for testing.

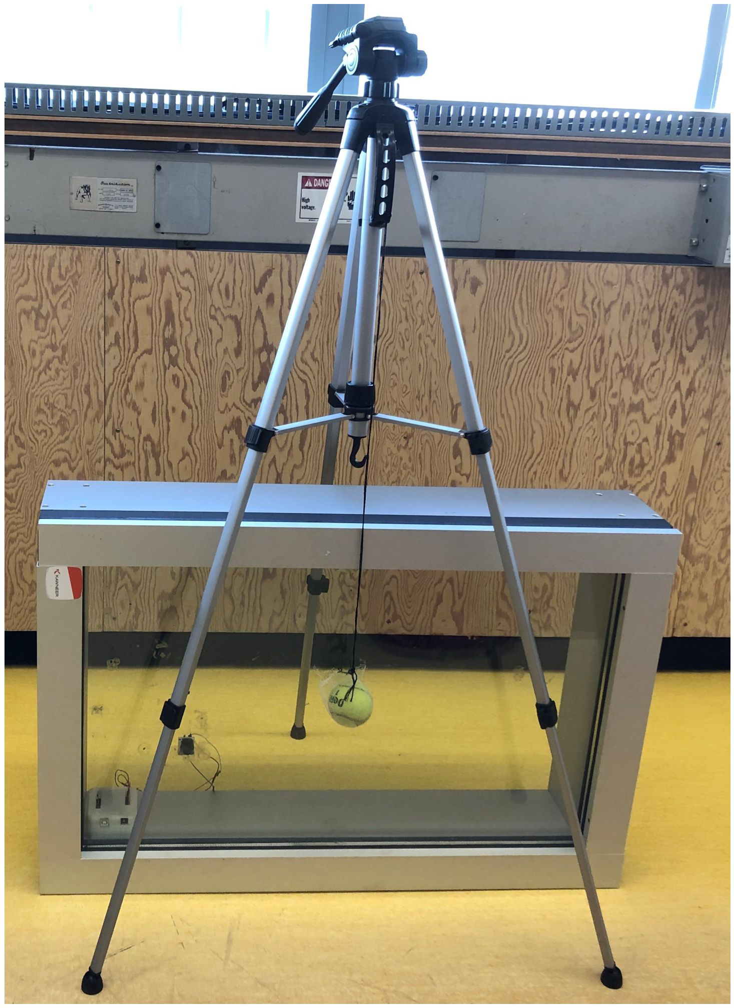

Figure C1: Photo of Mock Bird Used for Validation Tests

Pendulum Setup Procedure

Apparatus

The pendulum is constructed using the following apparatus:

1. Mock bird (Section 2.1)

2. String with varying length
3. String bag to hold mock bird, with secure mounting points for string attachment
4. Protractor
5. Camera tripod

Procedure

The pendulum should be assembled using the following steps:

1. Place the mock bird (1) inside the string bag (3).
2. Ensure the string (2) is of appropriate length for the bird impact location desired. Shorter strings raise the location of the impact on the test window, and longer strings lower the location of the impact on the test window.
3. Attach the string (2) to the string bag (3) containing the mock bird (1).
4. Attach the other end of the string (2) to a secure mounting point on the top of the tripod (5).
5. Ensure the pendulum is able to swing freely in a manner that allows it to impact the window unimpeded.

6. Use the protractor (4) to set the beginning angle of the mock bird (1) to attain the desired impact speed (Table C1, C2)

To ensure simulated impacts occur at the desired location on the test window, allow the mock bird to hang freely. Position the tripod so the mock bird is positioned at the desired horizontal location. Adjust the height of the tripod to ensure the simulated impact occurs at the appropriate vertical location on the window. This should be set as appropriate for each test that is conducted.

Pendulum Setup Calculations

To perform bird impacts using the pendulum, the string should be held taut at a drop angle appropriate for the speed required, calculated for the 18g ball in Table C1 and the 57g ball in Table C2. Due to the nature of the pendulum design, it is more accurate to use starting angle instead of height for ensuring the correct impact energy is attained. The angle is calculated using the following equation:

$$\theta = \arcsin \frac{h_{max} - h}{h_{max}}$$

Where:

h_{max}**:** The drop height of the mock bird from Table C1 and C2

h**:** The desired drop height

θ**:** The angle measured from the pendulum resting position

The angles required for the different drop heights of both 18g and 57g mock birds are shown in Tables C1 and C2.

Table C1: Pendulum Drop Angles of 18g bird with String Length of 1.9m.

Speed Label	**Mock Bird Speed (m/s)**	**Drop Height (m)**	**Pendulum** θ **(deg)**
1-High Speed	6.2	1.9	90
2-Medium Speed	3.83	0.75	52
3-Low Speed	1.7	0.15	23

Table C2: Pendulum Drop Angles of 57g Bird with String Length of 0.60m.

Speed Label	**Mock Bird Speed (m/s)**	**Drop Height (m)**	**Pendulum** θ **(deg)**
1-High Speed	3.43	0.60	90
2-Medium Speed	2.10	0.22	52
3-Low Speed	0.94	0.045	23

Appendix D: Ideal Environment Test

Varying Sensor Placement Test

Purpose

The purpose of this experiment is to find an acceptable placement of the accelerometer on the window by performing drops at various location on the window while fixing the location of the impact shown in Figure H1. These experiments are designed to mimic the ideal conditions in which the system will operate at the UBC Vancouver campus.

Apparatus

The apparatus for this experiment includes:

- The test window
- A window mount
- A pendulum that will consist of a mock bird (Validation appendix) and a string
- The microcontroller (Design Document, Section 3.3)
- The accelerometer (Design Document, Section 3.1.1)

It is noted that the common kinglet weighs approximately 7g, while we will be using a mock bird (Appendix B). This is done to limit drop heights required, and is accounted for in later calculations. The test window is set up according to Figure (Figure C1). The sensors are connected according to Figure 16, in section 7.1.

Procedure

1. Verify the mass of the mock bird and attach the bird to a string with a measured length to the pendulum frame. Attach the pendulum frame, shown in Figure C1, to the test window.

2. Place the accelerometer in location 1 shown in Figure D1 and connect to the microcontroller according to the schematic in Figure 14, section 7.1.

3. Drop the mock bird onto the approximate area marked by blue circle in Figure D1 from 90 degree angle to simulate the speed of 6.7m/s (which is listed in Table C2 and Table B2. Perform two impact. Save the signal for processing.

4. Repeat Step 3 after changing the sensor location to loca-

tions 2-7.

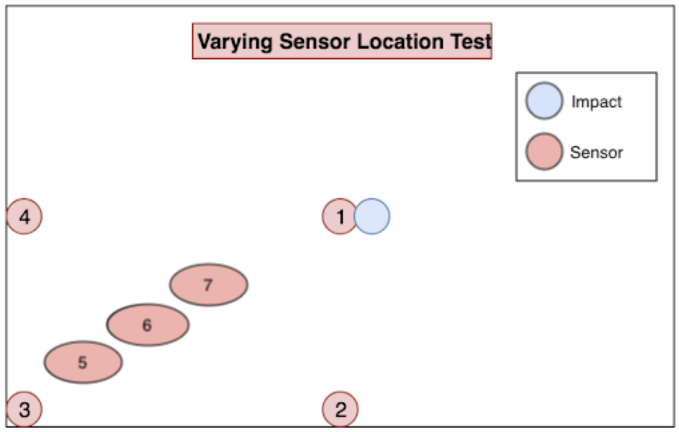

Figure D1: Drops Performed at Varying Sensor Location(red) While Fixing the Impact Location (Blue)

Observations

The maximum peak-to-peak voltage and frequencies are recorded in Table D1.

Table D1: Results from Varying Sensor Placements

Location	**Maximum Peak-to-Peak Voltage(V)**	**Dominant Frequency(Hz)**
1	0.5736	82.5, 165
1	0.593	82.5, 165
2	0.2449	82.5,120,165
2	0.2905	82.5,120,165
3	0.1901	82.5,137,176.5
3	0.1998	82.5,137,176.5
4	0.3062	82.5,165
4	0.3203	82.5,165
5	0.2933	82.5,137.5, 167.5,257.5
5	0.2739	82.5,167.5 257.5
6	0.3062	82.5,120,165, 257.5
6	0.3094	82.5,167.5 260
7	0.3803	82.5,165, 257.5
7	0.3642	82.5,167.5 257.5

In order to find an acceptable location for the accelerometer, the distance between the impact location and the sensor placement location is plotted against the maximum peak-to-peak voltage as shown in Figure D2.

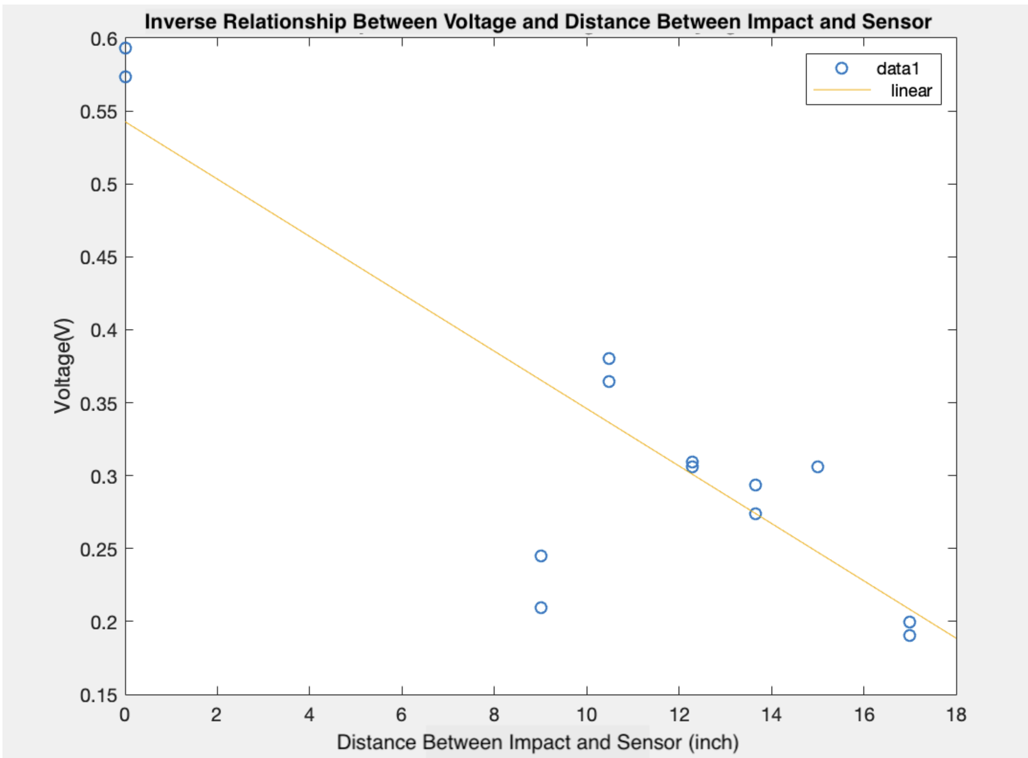

Figure D2: Scatter Plot with Best Fit Line of Voltage vs Distance by Varying Impact Location

From the varying sensor placement test, the accelerometer test shows a correlation between the sensor location and voltage. The further the distance between the impact and the sensor, the lower the voltage. While the majority of the data points fall along the best fit line that demonstrates an inverse relationship between the voltage and distance, there is an outlier when the distance is 9 inches. This outlier is from impacts at location 2.

Potential causes of the outlier could be dampening due to the rigidity of the metal window frame. In addition, the closer the sensor is to the frame the lower the resulting voltage as displayed in Table D1.

Conclusion

Based on the results and analysis summarized above, the acceptable sensor placement location, as indicated by the figure below, is at least 3 inches away from both frames. Therefore, the accelerometer should be at least 3 inches away from the frames in any direction for an voltage output at least 20 times the noise floor. In addition, for the best coverage of window for impact detection, it is better to place the sensor as close to the center (location 1) as possible. Figure D3 displays the acceptable locations for the sensor placement on the test window.

Figure D3: Acceptable Sensor Placement Locations Indicated by Green

Varying Impact Location Test

Purpose

The purpose of this varying impact location test is to identify the voltage and frequency characteristics at different impact location on the window, while fixing the location of the sensor at 6 inches away from the frame.

Apparatus

The apparatus for this experiment includes:

- The test window
- A window mount
- A pendulum that will consist of a mock bird (Validation appendix) and a string
- The microcontroller (Design Document, Section 3.3)
- The accelerometer (Design Document, Section 3.1.1)

Procedures

1. The test is conducted as follows: Set up testing environment according to Figure 14 section 7.1, with the accelerometer in the location marked for the sensors(red) shown in Ideal environment tests set-up shown in D3.

2. Verify the mass of the mock bird and attach the bird to a string with a measured length to the pendulum frame. Attach the pendulum frame, shown in Figure C1, to the test window.

3. Drop the mock bird onto the approximate area marked by blue circle in Figure D4 from 90 degree angle to simulate a speed of 6.7m/s (Drop Height 1 listed in Table C1). Perform two impact. Save the signal for processing.

4. Repeat Step 3 for for locations 2-6.

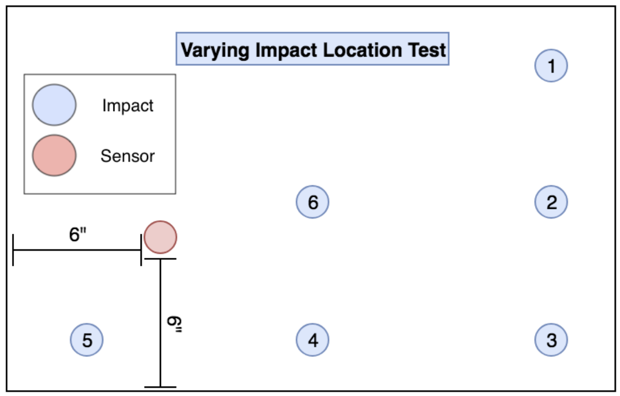

Figure D4: Drops Performed at Varying Impact Location(Blue) While Fixing the Sensor Location

Observations

The maximum peak-to-peak voltage and frequencies associated with each impact location are summarized below.

Table D2: Results from Varying Impact Locations

Location	**Maximum Peak-to-Peak Voltage**	**Dominant Frequency**
1	0.2997	120,256
2	0.4318	120,256
2	0.3996	120,256
3	0.3738	82,165,230
3	0.3964	82,165,230
4	0.3964	82,165,230
4	0.2997	82,165,230
5	0.4157	82,120, 257
5	0.3899	82,120, 257
6	0.5736	82,120
6	0.593	82,120

The distance between the impact location and the sensor placement location is plotted against the maximum peak-to-peak voltage as shown in Figure D5. No discernible correlation is established between impact location and sensor placement in terms of maximum peak-to-peak voltage.

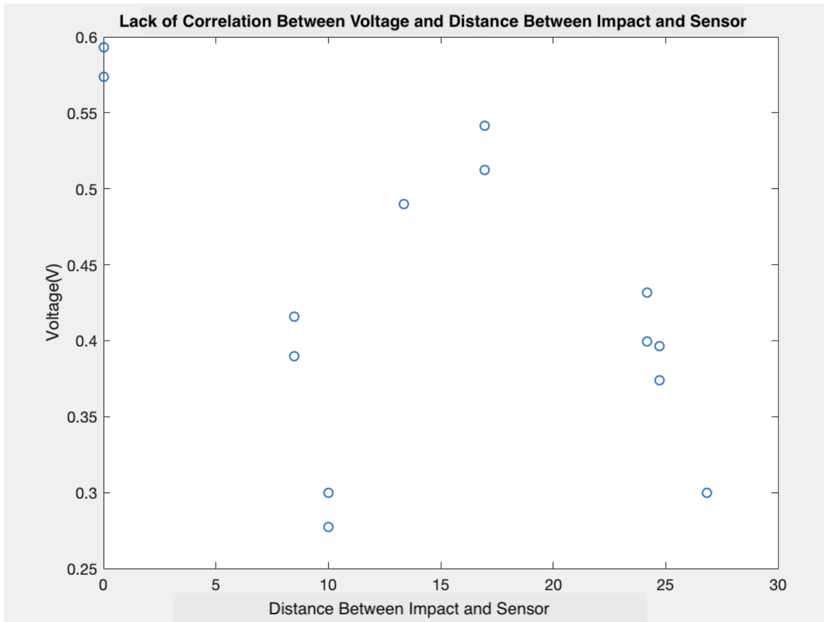

Figure D5: Scatter Plot of Voltage vs Distance by Varying Impact Location

The voltage range of the signals recorded by the accelerometer is from 0.1901V to 0.593V. The dominant frequencies of the simulated impacts are identified as 82.5Hz, 120Hz, 165Hz, and 260Hz. These frequencies consistently appear at a variety of impact locations.

Conclusions

This test is helpful in determining the voltage threshold and frequency ranges for the detection algorithm outlined in section 3.2.

For the accelerometer, the voltage ranges from 0.1901V to 0.593V. Dominant frequencies are also identified: 82.5Hz and 165Hz, 120Hz, 137Hz, 260Hz. These frequencies appear repeatedly in different impact locations.

Appendix E: Non-Ideal Environment Test

Human Noise Disturbance

Purpose

The purpose of the human noise disturbance test is to identify the effects of noise on the signal's characteristics such as voltage and frequencies. The results of this test will help finalize the voltage thresholds and frequency ranges in the detection algorithm to account for real-world operation scenarios.

Apparatus

- a UE WonderBoom bluetooth speaker
- Decibel X application for iPhone
- 2 iPhones
- Ideal environment tests set-up shown in Appendix D

Procedure

The human disturbance is created following these steps:

1. Turn on the UE WonderBoom speaker and connect it to an iPhone with bluetooth

2. Place the bluetooth speaker 3 meters away from the back of the window

3. Play the test sound on the iPhone connected to the speaker(30)

4. Take the second iPhone, open Decibel X, and measure the noise level next to the window

5. Adjust the volume of the iPhone playing the sound until the decibel meter on the second iPhone reads 60-70dB

6. Place the accelerometer the position indicated by the red circle in Figure D1 and connect to the microcontroller according to the schematic in Figure 14, section 7.1.

7. Drop the mock bird onto the approximate area marked by location 1 (blue) in Figure D1 from Drop Height 1 listed in Table C1. Perform two impact. Save the signal for processing.

8. Repeat Step 7 for location 6 indicated by Figure D1.

Observations

The observations are summarized below.

Table E1: Summary of Maximum Peak-to-Peak Voltage with 70dB noise in the Background

	Maximum Peak-to-Peak Voltage(V)
Best case w/noise	0.5221
worst case w/noise	0.2224
Best case: No noise	0.5736
Worst case: No noise	0.2997
Noise Floor: Human Noise	0.0161

As shown from Table E1 and Figure E1, the strength of the noise floor is negligible compared to the strength of the impact signal. Therefore, it should not have significant effect on the impact signals, which is confirmed below.

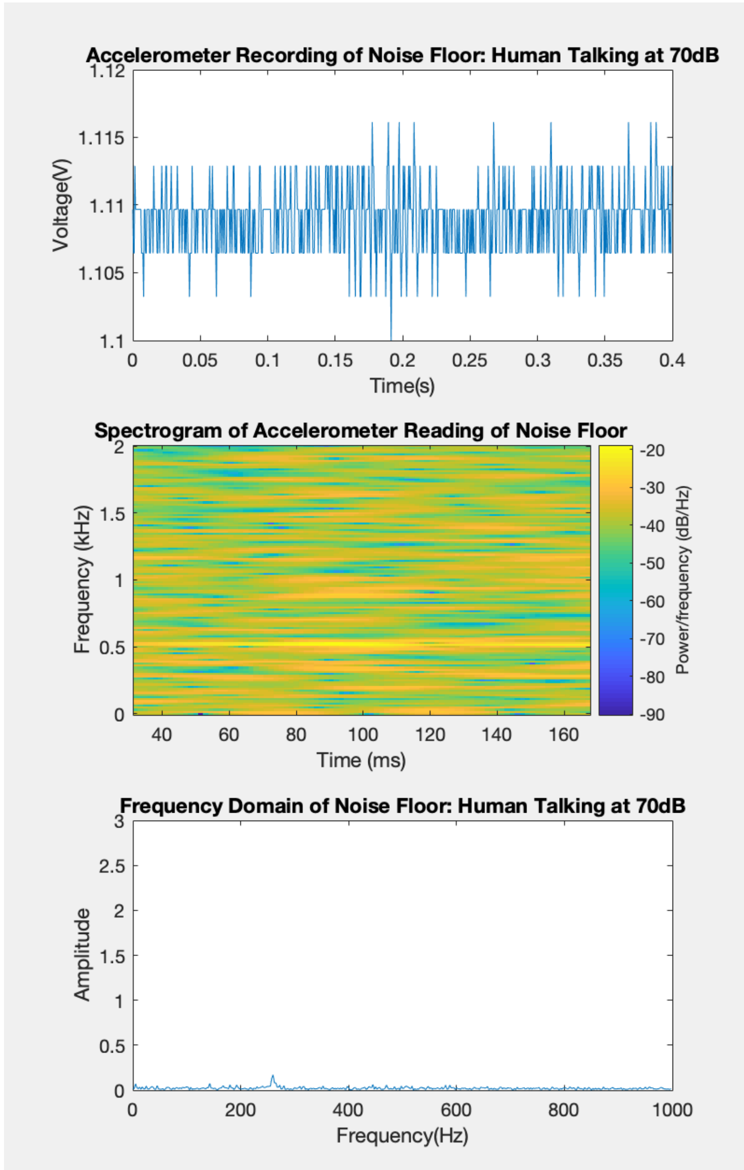

Figure E1: Noise Floor Measurement of Human Talking at 70dB

Figure E1 shows the spectrogram and and the FFT of the background noise with Human Talking at 70dB. Compared to the ideal environment background noise (Figure 5 at Section 2.3.1), there is a frequency peak at around 270Hz, which may be caused by a vibration due to the loud human noise. However, when we look at the amplitude at frequency domain, the highest peak is around 0.09, which can be ignored compared to even the worst case, which have all four of its peaks over 1.3 when we have small impact at the edge (see Figure 7 at section 2.3.2).

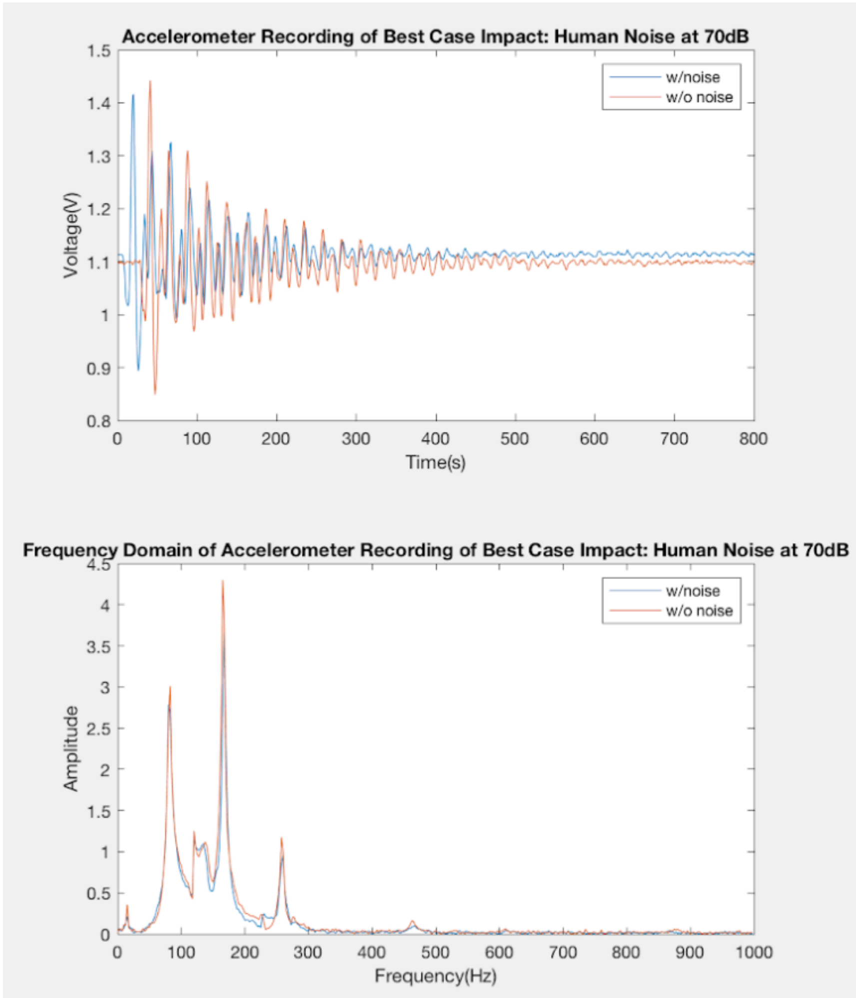

Figure E2: Comparison of Signals with and without Noise disturbance

The voltage of the impact signal in the time domain are relatively consistent, with the strength of the signal in non-ideal environment slightly lower than ideal environment.

The human noise disturbance dampens the voltage and by about

8% in the best case impact and the about 25%. The noise floor is 3% of the best case impact and 7% of the worst case impact with noise. In the frequency domain, the locations of the dominant peaks remain constant, while the signal in ideal environment having higher amplitude than the one in non-ideal environment at those peaks. The worst case impact demonstrates the same characteristics.

Conclusion

Human noise disturbance dampens the strength of the signal. Therefore, the voltage threshold in the detection algorithm should be changed accordingly to account for the noise. There's no effect on the frequencies ranges.

Rain

Purpose

The purpose of this to examine the effect of rain on the impact signals.

Apparatus

- a 15ft garden hose

- a hose spray nozzle
- duct tape
- 1 garbage bag
- Ideal environment tests set-up shown in the Appendix D

Procedure

1. Connect one end of the hose to the hose spray nozzle, and the other end to the water outlet
2. Tape the garbage bag to the back side of the window as shown in Figure E3.
3. Place the accelerometer the position indicated by the red circle in Figure D1 and connect to the microcontroller according to the schematic in Figure 14, section 7.1.
4. Turn on water and aim nozzel at the window.
5. Drop the mock bird onto the approximate area marked by location 1 (blue) in Figure D1 from Drop Height 1 listed in Table C1. Perform two impact. Save the signal for processing.
6. Repeat Step 7 for location 6 indicated by Figure D1.

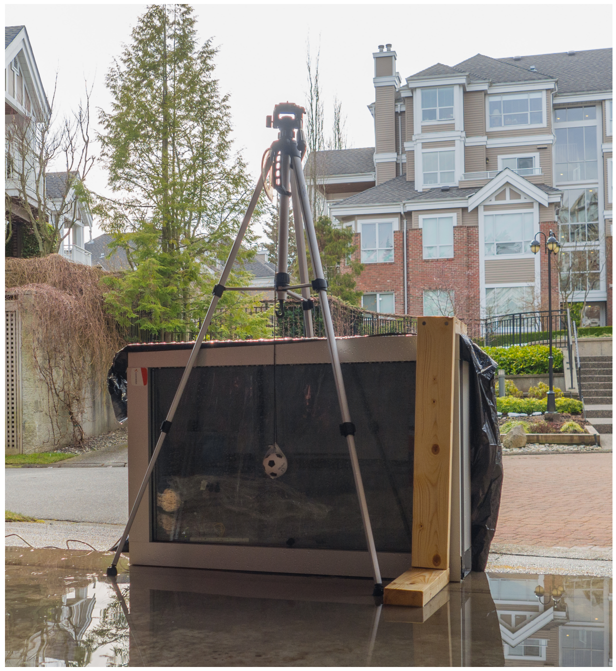

Figure E3: Full Rain Test Setup

Figure E4: Window with Garbage Bag Sealing and Rain

Observations

Table E2: Summary of Maximum Peak-to-Peak Voltage with Rain in the Background

	Maximum Peak-to-Peak Voltage(V)
Best case w/noise	0.3642
worst case w/noise	0.1192
Best case: No noise	0.5736
Worst case: No noise	0.2997
Noise Floor: Light Rain	0.0097

The rain disturbance dampens the voltage and by about 36% in the best case impact and the about 60%. The noise floor is 3% of the best case impact and 8% of the worst case impact with noise. As shown from Table E2 and Figure E5, the strength of the noise floor is negligible compared to the strength of the impact signal. However, the strength of the signal is dampened significantly.

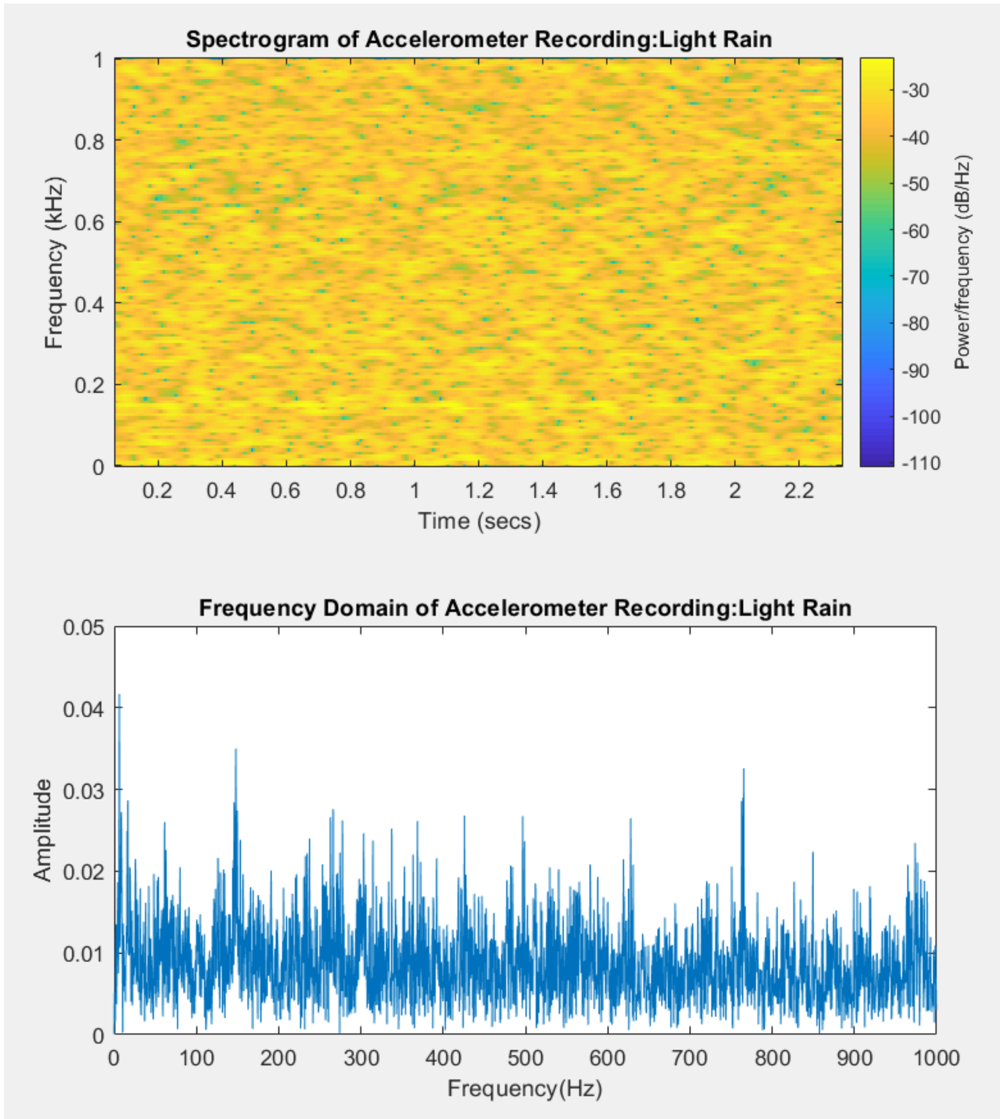

Figure E5: Noise Floor Measurement of Rain

As shown in Figure E5, the rain generates vibration with random frequency peaks with amplitudes less than 0.04 which can be ignored compared to the ideal environment background noise(Figure

6 at Section 2.3.1),

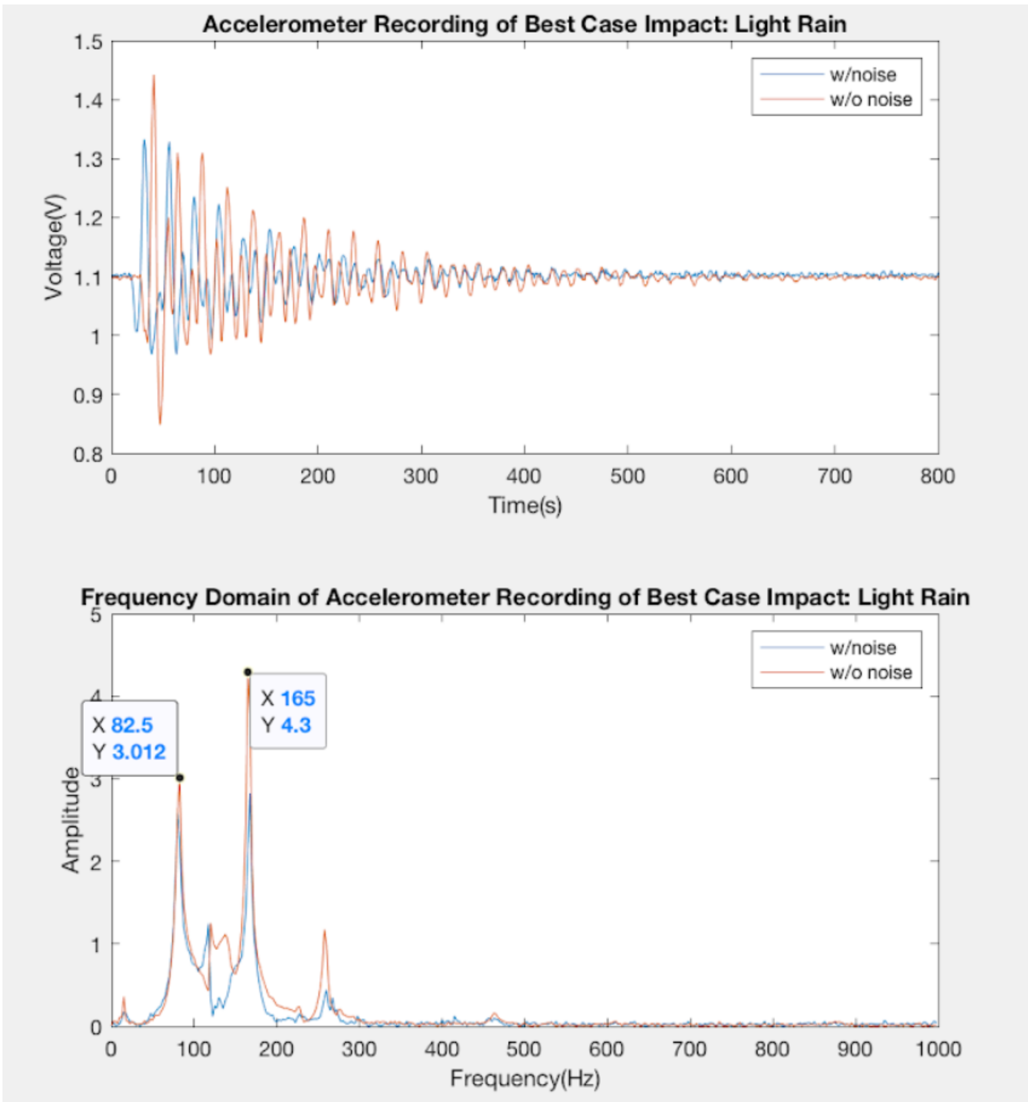

Figure E6: Comparison of Signals with and without rain disturbance

The voltage of the impact signal in the time domain is dampened significantly.

In the frequency domain, the locations of the dominant peaks remain constant, while the signal in ideal environment having higher amplitude than the one in non-ideal environment at those peaks. The worst case impact demonstrates the similar characteristics.

Conclusion

In conclusion, the maximum peak-to peak voltage difference of an impact is lower in non-ideal environment compared to ideal environment and the voltage threshold in the detection algorithm will be updated accordingly to account for possible scenarios with rain. The dominant frequencies remain constant.

Appendix F: Impact Data Processing

In order to determine an actual bird impact, a series of mock bird impact tests are performed to figure out the characteristics such as duration and frequency range. For the Discrete Time Fourier Transform we use the algorithm of fast Fourier Transform to calculate(4).

The process of calculation is shown as below and more detail can be referred to the code(31).

1. Receive analog data from accelerometer at a rate of 2000Hz and store in a global array.
2. Convert the signal into voltage.
3. Remove the DC component by subtract the average voltage of stored data
4. Measure the voltage difference by subtracting maximum voltage by minimum voltage in the array
5. Measure the duration by setting top and bottom voltage threshold value and measure time when it dampens below that threshold
6. Find frequency peaks by using Discrete Time Fourier Transform to convert the signal in frequency domain

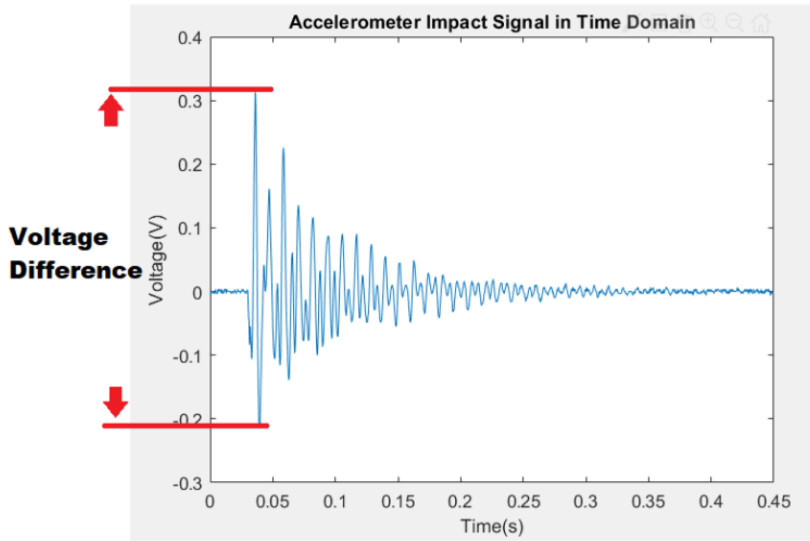

Figure F1: Accelerometer Impact Voltage in Time Domain

Figure F1 displays how voltage difference is measured, Figure F2 displays how signal duration is measured, and Figure F3 displays how frequency peaks are found.

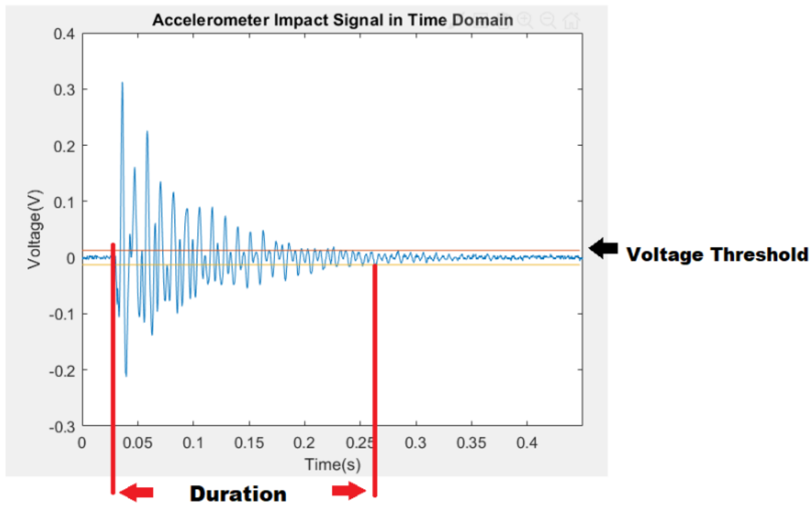

Figure F2: Accelerometer Impact Voltage in Time Domain

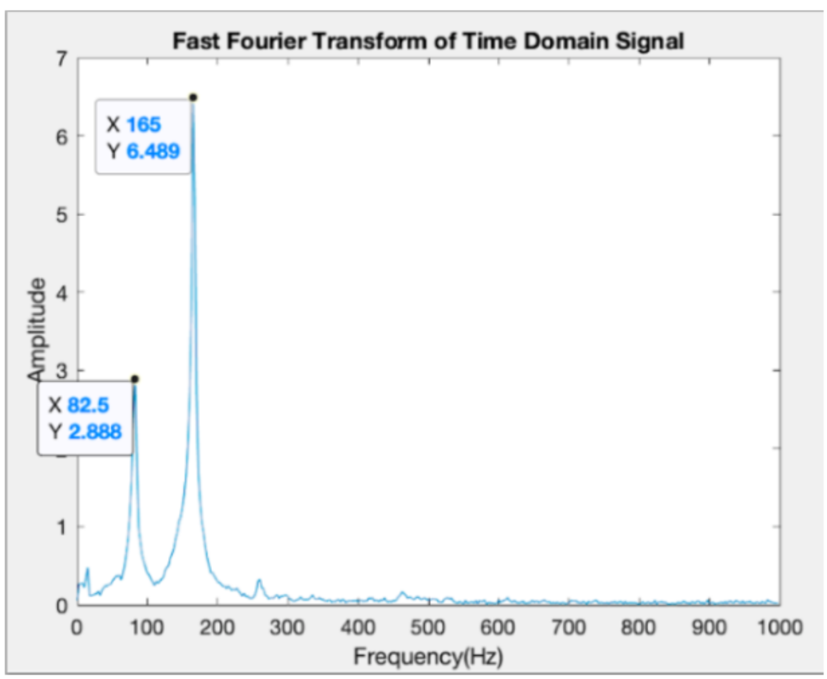

Figure F3: Accelerometer Impact Voltage Signal in Frequency Domain

Observations

By repeating mock bird impact testing and changing different material of mock bird (Section 2.1), we are able to characterize the features of a bird impact, summarized in Table F1.

Table F1: Impact Signal Patterns of Accelerometer

Test Speed	Voltage Difference (V)	Duration (s)	Frequency peaks (Hz)
Low	0.1297	1.5725	84,173
Medium	0.3258	0.2330	85,175
High	0.5539	0.2662	86,175
Minimum	0.0483	0.1175	85,178

Table F1 is to record the Voltage Difference, Duration and Frequency peaks of accelerometer signal. (For the specific value of speed, please refer to Appendix C: Table C2.)

Appendix G: Unimplemented Detection System Components

Four components were considered for implementation in the detection system, but were not included in the final design. These components are:

1. Digital filter for the accelerometer (Section 3.1.1)
2. Microphone sensor for impact detection
3. WiFi disconnection in the case of long-term loss of network
4. Damping Ratio Analysis for Detection Algorithm

These components were not included but could be useful in future iterations of the system. They are suggested as potential upgrades or additional functionality that could be added to improve various aspects of system function.

Digital Filter

A digital filter implemented in detection system removes the high-frequency components of signals produced by the accelerometer. These high-frequency signal components may interfere with the lower frequency analog signals in the 50-260Hz range that are indicative of a bird impact event. Therefore, a digital filter enhances the ability of the detection system to analyze signals from the sensor(32). The system is sampling the analog signals at 2000Hz, so signals of 1000Hz or less may be filtered digitally according to Nyquist's Sampling Theorem. As the maximum expected frequency on event of a bird impact is 260Hz, the digital filter is designed with a normalized cutoff frequency of 0.26.

A digital filter is implemented in the Arduino (Section 3.3) by multiplying sample and a defined number of preceding samples by a set of predetermined coefficients, then summing the result. The following filters were tested with recorded data from simulated bird impacts (Section 2):

1. Rectangle
2. Von Hann
3. Hamming
4. Blackman
5. Chebyshev
6. Kaiser

These filter types were simulated using the MATLAB windowDesigner command(33). Figure G1 compares the frequency domain output of each filter when applied to the same sample impact signal. Frequency domain output is the primary concern as it is used in the detection algorithm (Section 3.2).

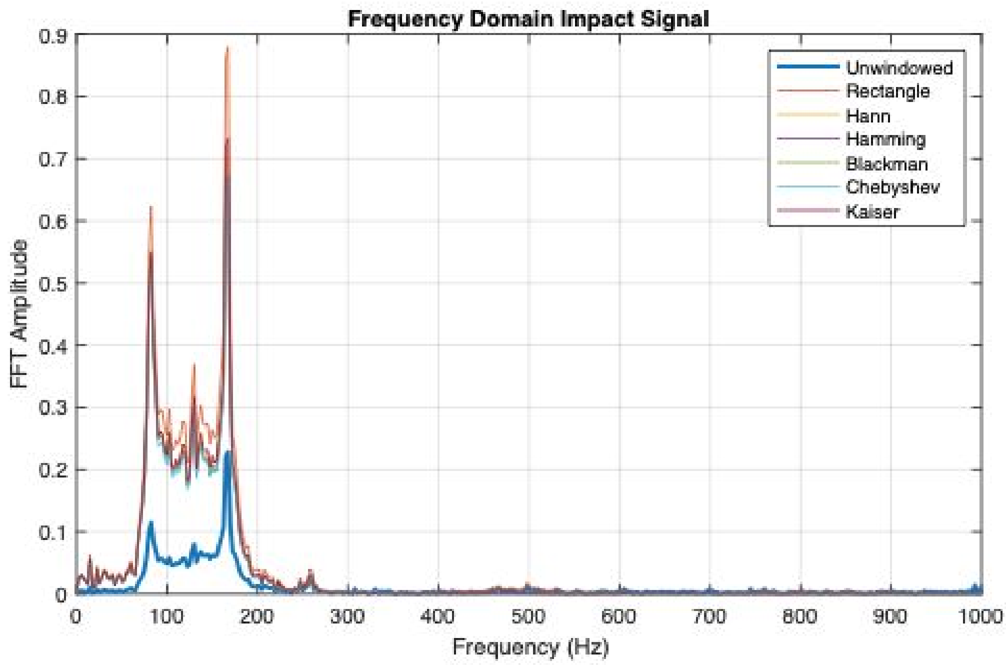

Figure G1: Frequency Domain Effect of Various Digital Filterse

Table G1 compares the characteristics of each filter when applied to a typical bird impact event signal. The digital filter properties are defined as:

Mainlobe Width: Double the point at which the signal power falls 3dB below the peak power.

Relative Sidelobe Attenuation: Difference between power of the mainlobe peak and peak power in sidelobes, measured in dB.

Leakage Factor: Ratio of power in the sidelobes of a signal to total signal power.

Length of Filter: The number of previous samples of the signal required to apply the filter, in addition to the most recent samples.

Table G1: Comparison of Digital Filter Properties with Bird Impact Signal

Digital Filter	**Mainlobe Width**	**Relative Sidelobe Attenuation**	**Leakage Factor**	**Length of Filter**
Rectangular	0.29688	-12.4dB	8.68%	6
Von Hann	0.25781	-31.6dB	0.05%	12
Hamming	0.25	-36.7dB	0.04%	11
Blackman	0.25	-59.1dB	0%	14
Chebyshev	0.26562	-100.0dB	0%	8
Kaiser	0.27344	-24.2dB	0.45%	8

The Chebyshev filter is recommended for use in the system due to having approximately 0% leakage and a cutoff frequency very close to the desired cutoff frequency. The Chebyshev filter for the system is defined using the following set of coefficients:

$$\begin{aligned} y(n) = {} & 0.0055x(n) + 0.0388x(n-1) + 0.1418x(n-2) + 0.3482x(n-3) \\ & + 0.6333x(n-4) + 0.8936x(n-5) + 1.0000x(n-6) + 0.8936x(n-7) \\ & + 0.6333x(n-8) + 0.3482x(n-9) + 0.1418x(n-10) \\ & + 0.0388x(n-11) + +0.0055x(n-12) \end{aligned}$$

To implement this filter in the detection system, these coefficients are programmed into the code. As samples are read from the detection system sensor (Section 3.1), the samples should be multiplied by the appropriate coefficients.

Microphone Sensor

The CMA-4544pf microphone sensor is one of the potential impact sensors of the detection system. Microphone sensors are known to have a wide range of applications in detecting vibrations(8). For example, microphones have been previously used for monitoring underground vibrations continuously and reliably(34). Since the microphone sensor must detect the audible sounds from bird collisions to satisfy FR1, the sensor must operate in the frequency range of human hearing (20 to 20,000Hz)(35). Considering the cost of the microcontroller, the sensors, and the other miscellaneous material, the budget of the microphone was determined to be less than \$10 to satisfy C1. The considerations for choosing a microphone sensor (36) are summarized in Table G2.

Table G2: Microphone Sensor Minimum Specification and Comparison

Feature	**Minimum Specification**	**CMA-4544pf**
Input	20 to 20,000Hz	20 to 20,000Hz
Operating Voltage Range	3.3 to 5V	3 to 10V
Cost	less than $10	$1.2

The microphone may improve the accuracy of the detection system in environments that were not tested in the development of the Bird Impact Detection System. If the variety of environments in which the system is expected to operate is increased in the future, the microphone may become useful as a backup sensor for the accelerometer. Therefore, it is recommended for addition to future iterations of the detection system.

WiFi Disconnection Handler

In validation testing of the Bird Impact Detection System, no situation was encountered where the wireless communication (Section 4) was disconnected for an extended period of time. Therefore, the detection algorithm (Section 3.2) does not account for the situation in which the communication system is inaccessible for an extended period of time due to unforeseen circumstances. The Bird Impact Detection System currently utilises the UBC Visitor WiFi network (Section 4.3), which is kept consistently accessible by UBC IT services. Due to this, a contingency for extended loss of connection was not a priority in the detection system algorithm.

Future iterations of the system may be used outside of UBC Campus, or in locations on UBC Campus where it is more difficult to obtain a WiFi connection. If the system is planned for future use in these or other similar circumstances, it is recommended that the detection system algorithm be altered to account for impacts that occur while the communication system cannot be accessed. Such an algorithm would store a record of impact events that are not able to be sent immediately to data storage (Section 5) to be sent once a connection is reestablished.

Damping Ratio Analysis for Detection Algorithm

In the current detection algorithm, the method to determine the duration of an impact is by counting the amount of the time between the maximum peak-to-peak voltage until the signal settles back to noise floor as shown in Figure F2. However, this method require taking more data samples in order to capture the full duration of the signal. Another method that would allow us to identify the damping characteristics of an impact signal.

Motivation The damping ratio is a character unique to the impact signal and can be used to effectively distinguish between impact and other disturbances. A bird impact has a distinctive signal profile different from other disturbances in the environment such as rain or human talking. As shown in the Figure G2 and G3, the envelope of the impact signals display a clear damping characteristic that is different from other disturbance signals.

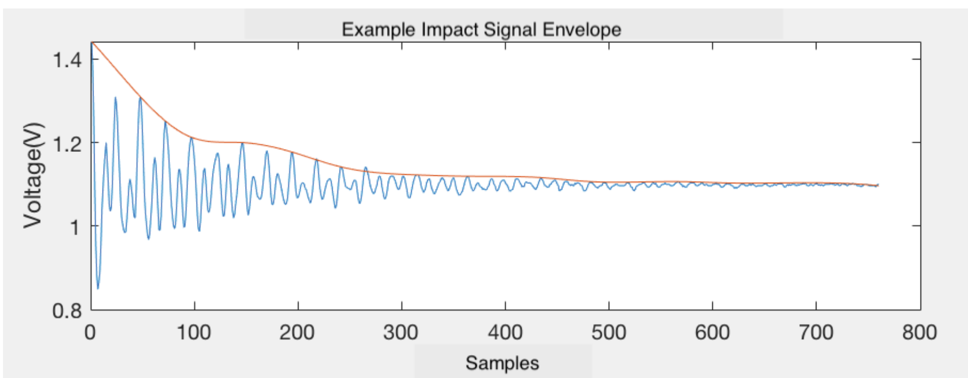

Figure G2: Example Signal of Impact

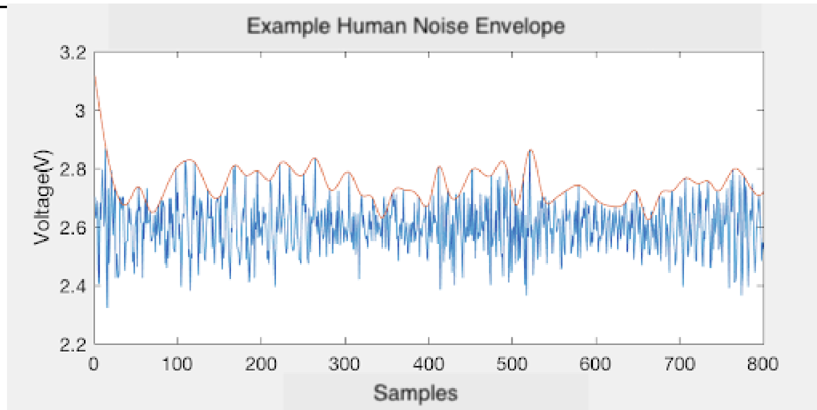

Figure G3: Example Signal of Human Noise

How to Find the Damping Ratio in Matlab

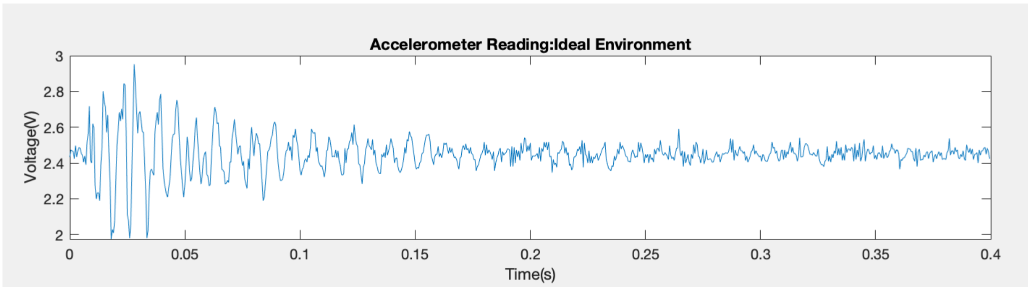

Figure G4: Example Signal of Impact

1. Starting with an example signal shown in G4, we need to clean up the time-domain signal by eliminating all data entries before the index that corresponds to maximum voltage,in order to get an envelope of the signal that pertains to an exponential decay.

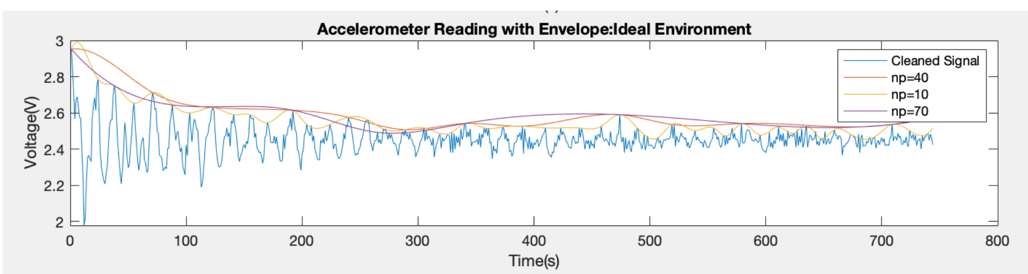

Figure G5: Example Signal of Impact

2. Use the "envelope" function $[yupper, ylower] = envelope(x, np,' peak')$ in Matlab, to extract the upper envelope of the signal. The envelope function uses spline interpolation over local maxima separated by an adjustable number of samples. *yupper*

is the variable denoting the upper envelope. np is peak separation, which is the number of sample over which the local maxima are separated. The bigger the np, the smoother the envelope, as shown in Figure G5.

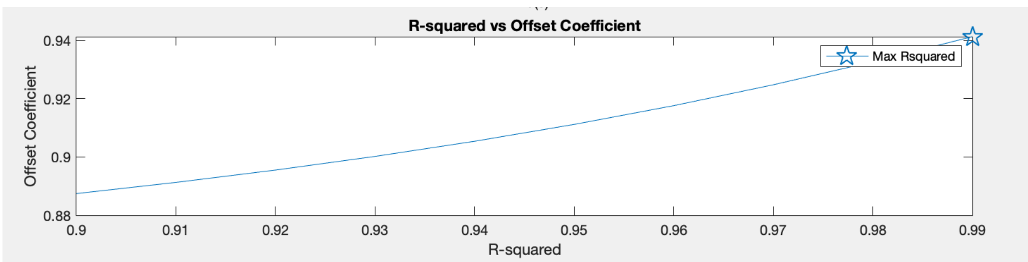

Figure G6: Different Configuration of Envelope Based on Peak Separation denoted by np

3. Using the Curve Fitting Tools in Matlab, we can generate the an exponential curve fit to the envelope. Since the curve fitting function is $y = a * e^(b * x)$, it is important to eliminate the offset to allow for the constant term that is not present in the function. The R-squared parameter is the the proportion of the variance in the dependent variable that is predictable from the independent variable, which is important for determining the quality of the fit. The closer R-squared is to 1, the better the fit. This process is shown in Figure G6.

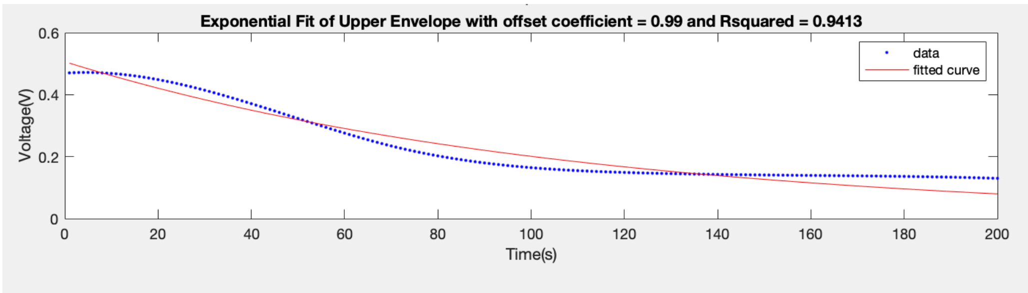

Figure G7: Finding the Largest R-squared Value

4. Since we are looking at the damping ratio, using visual inspection of the time domain signal, we can see that the samples between 0 to 200 display damping characteristics. Therefore, we can apply curve fit to the 200 samples and discard the rest. The resulting R-squared value is 0.94, which is a good fit.

5. Using Matlab to automate the process for more data, we can define the range of damping ratio and apply to the identification algorithm.

This method is not currently implemented because the arduino's limited memory does not allow such heavy computation. However,with a more powerful microcontroller such as an Raspberry Pi, such functionality can be achieved.

Appendix H: System Placement

Two options are available for the placement of the Bird Impact Detection system. These options are:

1. Placement inside the building in which the window is installed.
2. Placement outside the building in which the window is installed.

In both options, the sensor would be affixed directly to the glass of the window, and the microcontroller would be affixed directly to the metal frame (Section 7.2). Bird impacts were conducted in both conditions using the simulated bird impact setup (Section 2). Figure H1 compares the sensor voltage readings from impacts with the sensor placed on the inside of the window (red) and the outside of the window (blue). The sensor was affixed to the same horizontal and vertical position on the window for both the inside and the outside positions. The simulated bird impact was on the same location of the window for both sensor placements.

Repeated impacts are performed on both the inside and outside of the window and their peak-to-peak voltage are comparable as

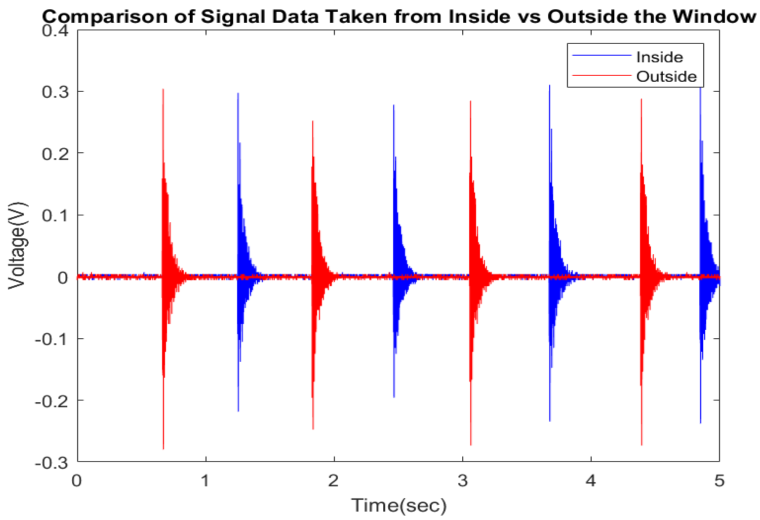

Figure H1: Comparison of Repeated Impact Signals Performed Inside and Outside of the Window

shown in Figure H1. This is to show that placing the sensor on inside or outside has little effect on the accelerometer signal.

To reduce the complexity of the system, the sensor is placed on the inside of the window. This decision is reflected in the overall system installation (Section 7). It is assessed that this reduces complexity by the more controlled conditions inside of buildings compared to outside. If the system were placed outside, more strict design constraints would be required with regard to weatherproofing and access to power. A plan was created for the case of the system being placed outside, presented in Appendix L.

Appendix I: Microcontrollers Evaluated

The other options that were considered for the microcontroller are:

- Arduino MKR WAN 1300 (37)
- LinkIt Smart 7688 (38)

Table I1 compares these two microcontrollers to the Arduino Uno WiFi Rev2.

The Arduino MKR WAN 1300 does not provide enough built-in memory for the project, with regards to the worst-case maintenance needs. The LinkIt Smart 7688 was not chosen due to the necessity of adding an SD card for data storage. In addition, the Arduino Uno WiFi Rev2 is already familiar to the group members of Capstone Group 62. It has extensive online support for the functionality required for the project, reinforcing it as the microcontroller choice over the other options.

Table I1: Microcontroller Evaluation Comparison

Feature	**Minimum Specification**	**Arduino Uno WiFi Rev2**	**Arduino MKR WAN 1300**	**LinkIt Smart 7688**
Analog Pins	1	6	7	12
Output Voltage	3.3V	3.3V	3.3V	3.3V
Output Current	300μA	50mA	7mA	4mA
Clock Speed	520Hz	16MHz	48MHz	580MHz
Flash Memory	15kB	48kB	256kB	32MB
Memory Storage	33.6kB	6,144kB	32kB	SD Card
Onboard WiFi Module	Yes	Yes	No	Yes

Appendix J: Google Sheets Information

Google Sheets, provided by Google Drive(26), was considered as the second data storage method for the system. Google Sheets meets or exceeds all of the minimum specifications for data storage, so it provides a viable solution. In addition, Google Sheets is an accessible format for raw data storage that is familiar to the client, and is likely to be familiar to other potential users. It is also a free service provided by Google, as data stored in the Google Sheets application is unaffected by Google Drive free storage limits. Google Sheets does require data to be presented in HTTPS format to be parsed, meaning an API should be used to connect it to the detection system (Section 3).

However, while Google Sheets meets or exceeds all of the requirements of data storage (Section 5), issues were encountered in the implementation of Google Sheets alongside Cayenne (Section 5.3). While Cayenne was able to receive data packages reliably during validation testing, Google Sheets became unreliable when implemented within the detection system state machine (Section 3.2). Therefore, despite meeting or exceeding the minimum specifications defined, Google Sheets was not included in the final design of the system.

Appendix K: Database and UI Setup

A MyDevices Cayenne account is required to set up and access the features of the Cayenne database and UI. A free account may be registered at the MyDevices Cayenne website (39) to complete this setup.

To connect the Arduino Uno Wifi Rev2 (Section 3.3) to the Cayenne database, follow the tutorial provided on the MyDevices website(40). The tutorial for the Arduino Uno with a Wifi shield should be followed, ensuring the following global variables in the main code(31) match the values presented for the database:

1. MQTT Username
2. MQTT Password
3. Client ID
4. MQTT Server
5. MQTT Port

Name the device any desired, appropriate identifier. Ensure that the UBC Visitor WiFi connection is available, and that the channel in the tutorial code matches the desired channel for data transmission. Once the network and Arduino Uno WiFi Rev2 are ready, run the code from the tutorial on the device.

When the device is displayed as connected on the Cayenne dashboard, the custom widgets for the UI may be added. To add a custom widget, choose ‘device/widget’ from the ‘Add new. . . ’ drop-down menu, pictured in Figure K1. The ‘Custom Widgets’ option should be used to add the widgets for the system UI (Section 8). Note that the counter widget should already be added from the tutorial completed to add the device, and that widget names and channels may be changed later if needed.

Figure K1: Cayenne ’Add Widget’ Drop-Down Menu

The custom widgets for the UI are added as follows:

Numerical Counter: Choose the ‘Value’ widget. Name the widget with the device location identifier and ensure the correct device and channel are chosen. The data type should be set to 'Counter', with units of 'Analog'. Once complete, the 'Add Widget' button should be available if the device is connected. This will add the widget to the dashboard for use. Figure K2 displays the settings that should be used.

Line Chart: Choose the 'Line Chart' widget. Name the widget appropriately for the device location identifier and ensure the correct device and channel are chosen. The data type should be set to 'Counter', with units of 'Analog'. Once complete, the 'Add Widget' button should be available if the device is connected. This will add the widget to the dashboard for use. Figure K3 displays the settings that should be used. If desired, the y-axis scale may be adjusted.

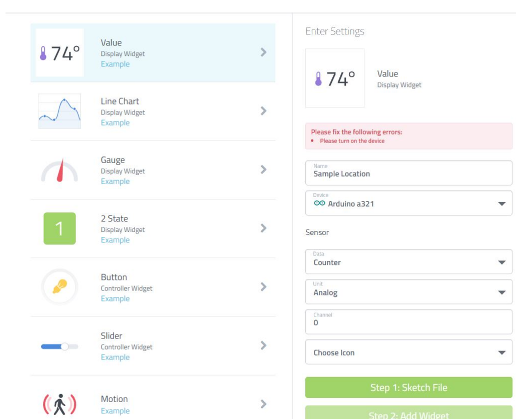

Figure K2: Settings for Cayenne Numerical Counter

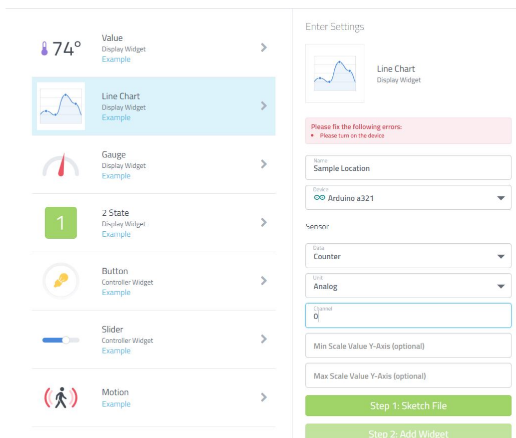

Figure K3: Settings for Cayenne Line Chart

Appendix L: System Waterproofing Plan

This is the installation method for the system if it is installed on the outside of a window. The system (Section 1) must be able to operate for seven days without need for maintenance to satisfy NFR2. Vancouver has 164 rainy days per year on average (41). The exposure of the system to rain or condensation is inevitable should the system be situated on a window. Waterproofing removes the risk of damage or breakage of the physical device on the window by way of exposure to water. Assuming that it rains every 2.2 days, our waterproofing method must be able to protect our system consistently from water exposure to enable our system to consistently detect bird impacts. This waterproofing plan includes how to waterproof each of the system components individually.

Microcontroller Waterproofing Solution

The Arduino system (Section 3.3) will be placed in a weather-resistant case. Holes will be drilled through the case so that the Arduino ports that are needed for the system will be accessible. Once required wires are in place, silicone or epoxy will be used as an effective way to seal to holes. The method of silicon waterproofing components of the system was evaluated as the implementation of silicon for the usage of waterproofing or sealing cracks is reliable. It is a solution that is ubiquitous and robust in areas of heat exposure, moisture and chemical use (42). The method of waterproofing for the Arduino provides the following features: lasts a minimum of 20 years(43).

Impact Sensors Waterproofing Solution

A layer of silicone or epoxy will be applied to the accelerometer to keep it from water damage. The method of silicon waterproofing components of the system was formulated as the implementation of silicon for the usage of waterproofing or sealing cracks is reliable. It is a solution that is ubiquitous and robust in areas of heat exposure, moisture and chemical use (42). The method of waterproofing for the impact sensor provides the following features: last a minimum of 20 years(43).