Powering Roller Coaster Sensors Via Piezoelectric Transducers

Group 25

- Kristopher Walters (EE)

- Juan Rodriguez (CpE)

- Richard Klenotich (EE)

- Nicholas Villalobos (CpE)

Motivation


Rich

To provide a inexpensive solution to power onboard sensors and devices on vehicles susceptible to vibrations.

Provide an accelerometer that does not require access to power on vehicle it was installed on, providing meaningful data to the user.

Goals and Objectives

Rich

To develop a sensory system that can be installed on a rollercoaster (a vehicle without onboard power) that requires minimal maintenance and provides meaningful data to the user.

- Requires no external power source (harvests own power)
- Transmit data quickly to the end user
- System divides power efficiently amongst the sensors.

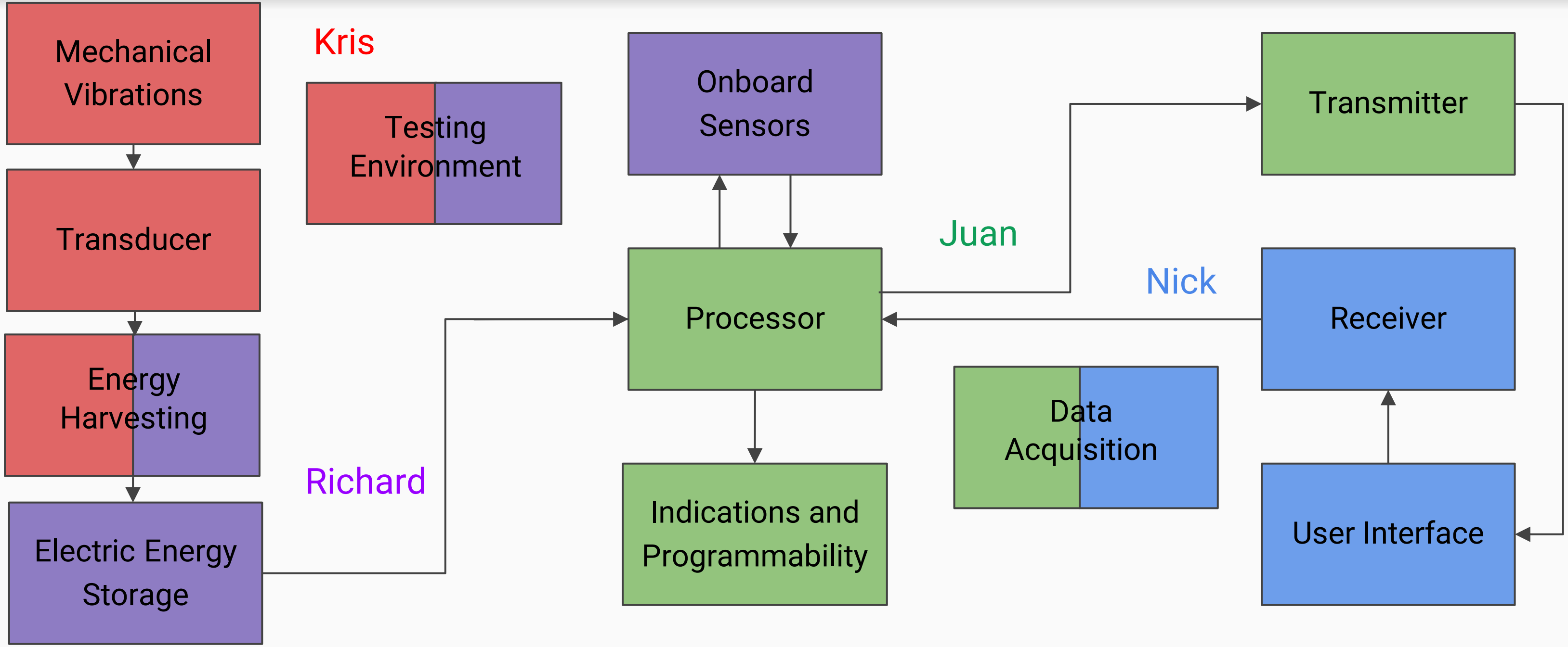
Specifications

Rich

- The system must be able to charge within 20 minutes
- The Bluetooth module must transmit all the data to the end user in less than 1 minute.
- The system needs to run for more than 2 minutes and 30 seconds on a single charge.
- Our entire budget must not exceed $700.

Design & Responsibilites Block Diagram

Kris



Work Distribution

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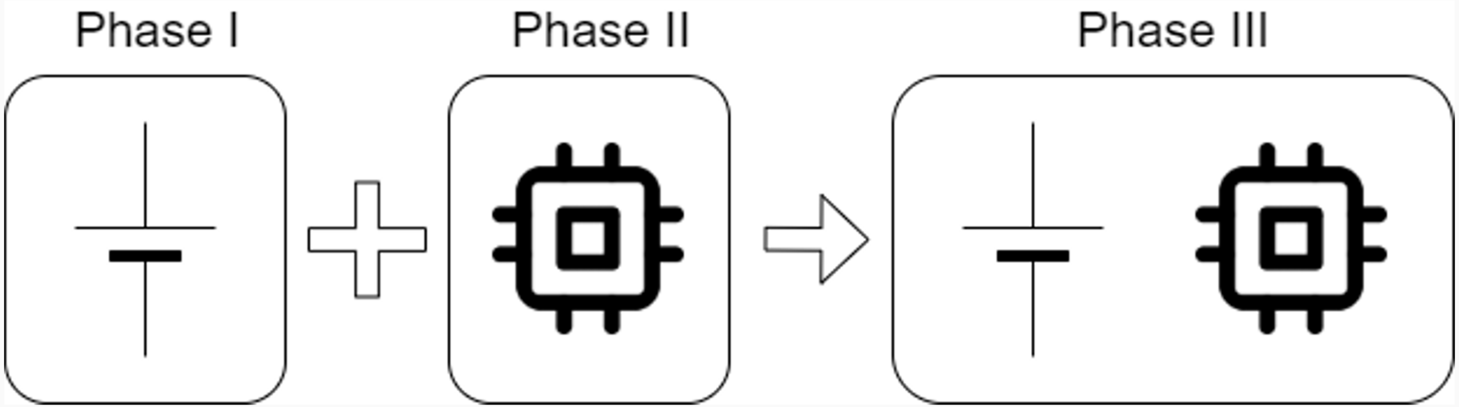


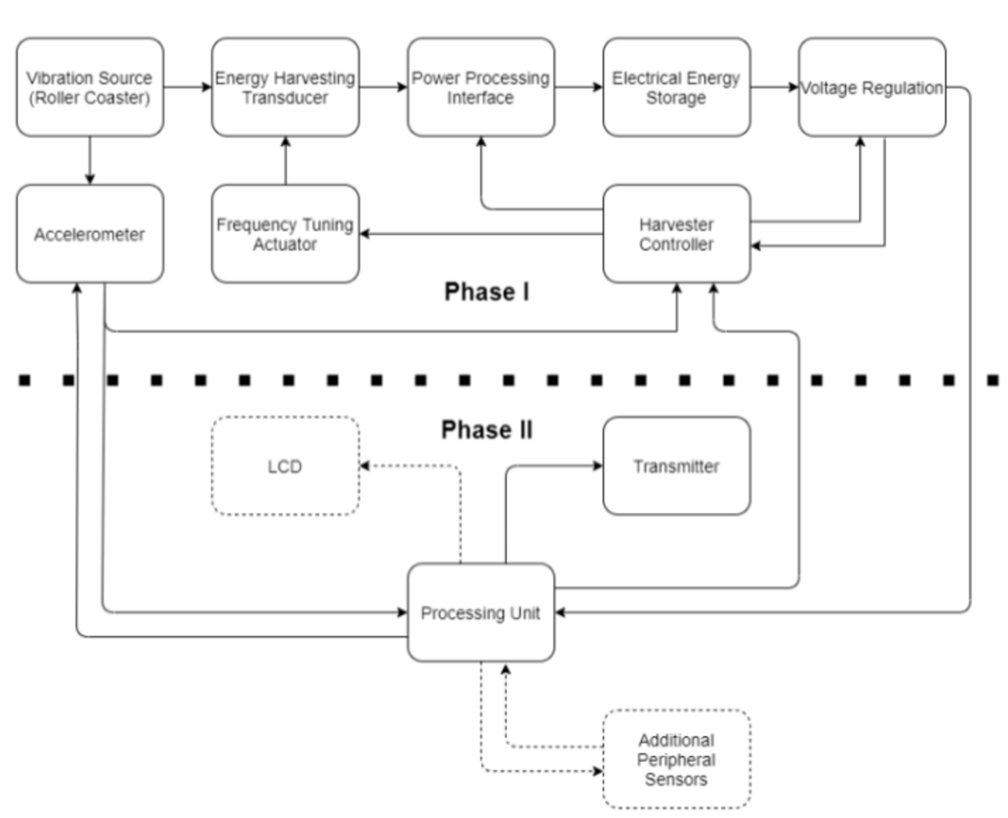
Phase I	Phase II	Phase III
Kristopher Walters	Juan Rodriguez	All Members
Richard Klenotich	Nicholas Villalobos	

Work Distribution Table

Primary	Secondary	Task	Phase Designation
Kristopher Walters	Richard Klenotich	Harvesting Vibrations (Piezos)	I
Richard Klenotich	Kristopher Walters	Harvesting Voltage	I
Richard Klenotich	Kristopher Walters	Energy Storage	I
Kristopher Walters	Richard Klenotich	Testing Environment	I, II, III
Richard Klenotich	Juan Rodriguez	Sensors	II
Juan Rodriguez	Nicholas Villalobos	Microcontroller	II
Nicholas Villalobos	Juan Rodriguez	Data Acquisition	II, III
Nicholas Villalobos	Juan Rodriguez	Mobile Application	II, III
Juan Rodriguez	Kris and Rich	PCB Design	III

Kris

Overall Design: Phase III



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Phase 1

Energy Harvesting Method

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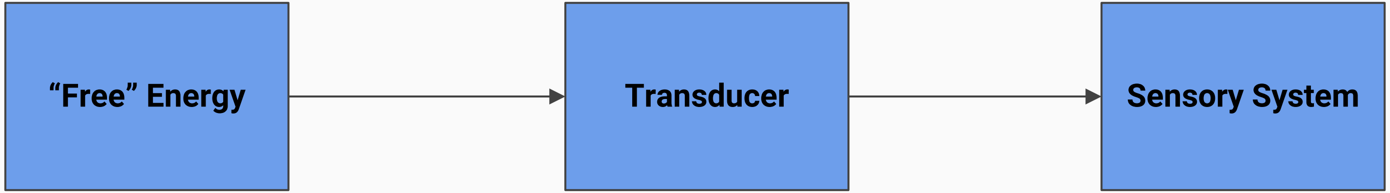
Convert "Free Energy" to usable power



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Selection of Sources

- Wind
- Solar
- Battery
- Heat
- Mechanical Vibrations

Mechanical Vibrations


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- Low Profile
  - Size
  - Exposure
- Low Vehicle Design Requirements
- All vehicles are subject to vibrations

Selection of Piezoelectric Transducers

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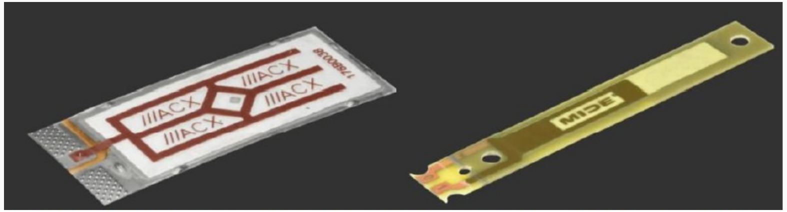
- Constant Mechanical Stress to AC Voltage
- Small Profile
- Cantilever Fashion
- Provides High Voltages with Minimum Deflection

Selected Piezoelectric Transducer And Harvesting Unit

Kris

S118-J1SS-1808YB S129-H5FR-1803YB



Transducer Model	Capacitance (F)	Runtime (s)	Downtime (s)	Amp Mag.	Critical Mag.
S118	940uF	Indefinite	-	70%	50%
S129	940uF	5.5	62	70%	-

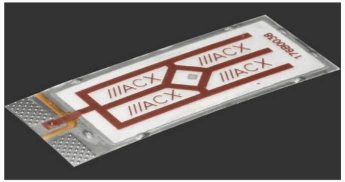
BOB-09946

Part #	S118-J1SS-1808YB	S129-H5FR-1803YB
Length (mm.)	55.4	55.4
Width (mm.)	23.4	23.4
Thickness (mm.)	0.46	0.74
Temperature Range	-60° C to 120° C	-60° C to 120° C
Mass (grams)	2.8	1.4
Capacitance (nF)	100	22
Rated Drive Voltage (+/-V) off of Resonance	120	200
Free Deflect (+/-mm)	0.80	0.23
Blocked Force (N)	0.20	0.06
Spring const (N/mm)	0.25	0.261
Resonant Freq (Hz)	130	175
Max Drive Volts @ Resonance (V)	10.0	10.0
EH Resonant Freq (Hz)	130	49
Open Circuit Output (+/- Volts/G)	6	4
Resistor Load (Ohm)	15700	18000
Output Voltage (V)	17.3	28.2
G rating (+/- G's)	8	8
Price Per Unit	$31.92	$43.63

Selected Piezoelectric Transducer And Harvesting Unit

Kris

S118-J1SS-1808YB



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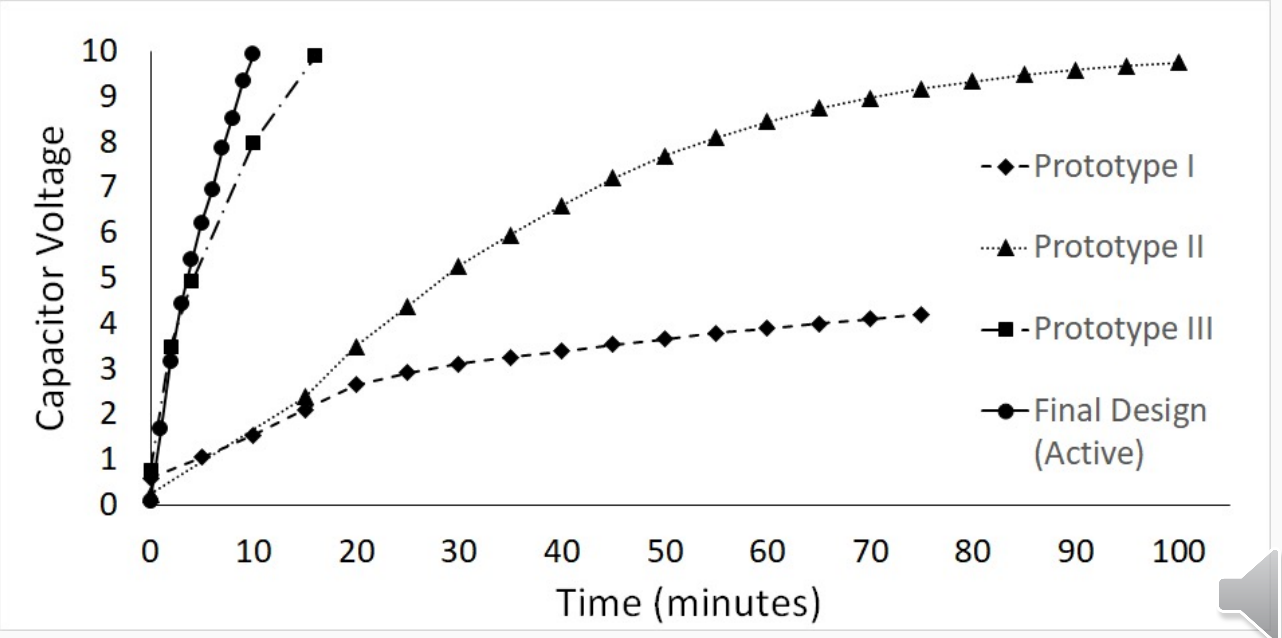


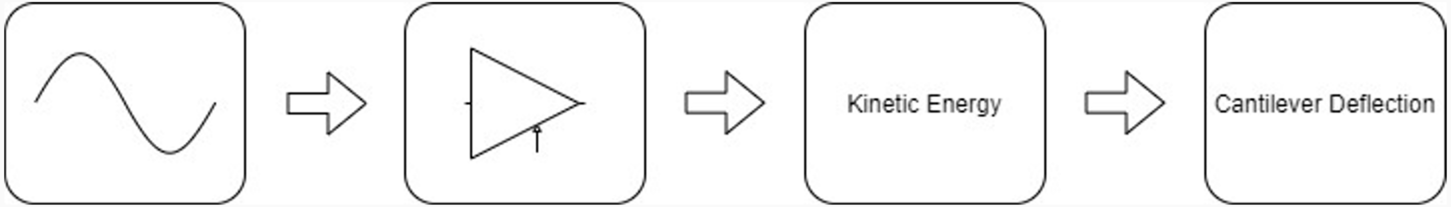
Phase 1 Difficulties


Kris

- Resonance
  - Generation of Power
  - Masses added to cantilever
- Method of Testing

Piezoelectric Transducer Test Method

Kris



Piezoelectric Transducer Test Method

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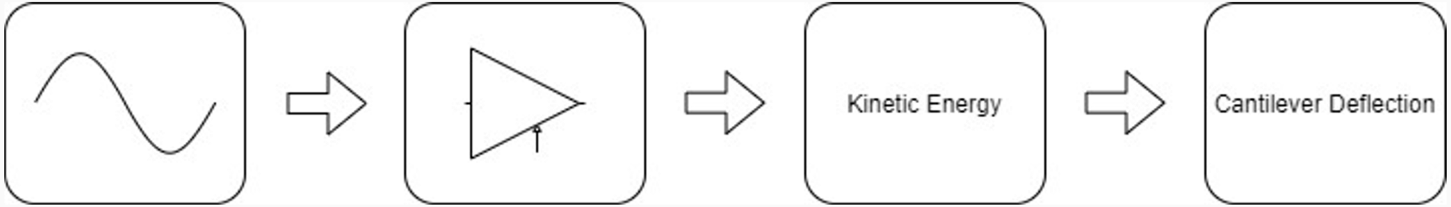
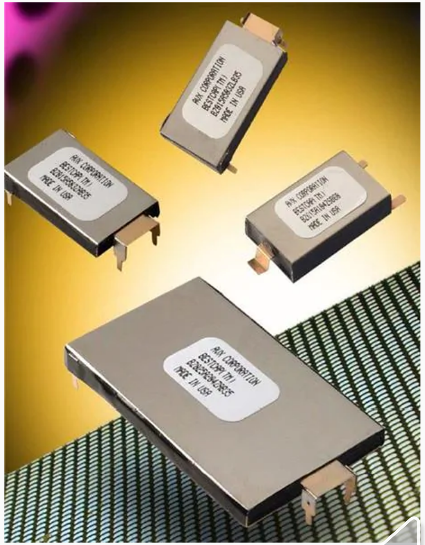


On-Board Energy Storage

Rich

BZ12GA124ZLBA2 - Supercapacitor

- 16 VDC Rating
- 120,000 uF Capacitance
- 160 mOhm ESR
- 48mm x 30mm size



Supercapacitor Comparisons

Rich

Name	Manufacturer/ Supplier	Output Voltage	Equivalent Series Resistance	Price
BZ12GA124ZLBA2 16 V Supercapacitor	AVX Corporation	16V	160mOhm	$37.90
BZ12GA124ZAB 16 V Supercapacitor	AVX Corporation	16V	160mOhm	$94.21
FC S0H224ZFTBR24 5.5 V Supercapacitor	Kemet	5.5V	50Ohm	$3.09

Phase 2

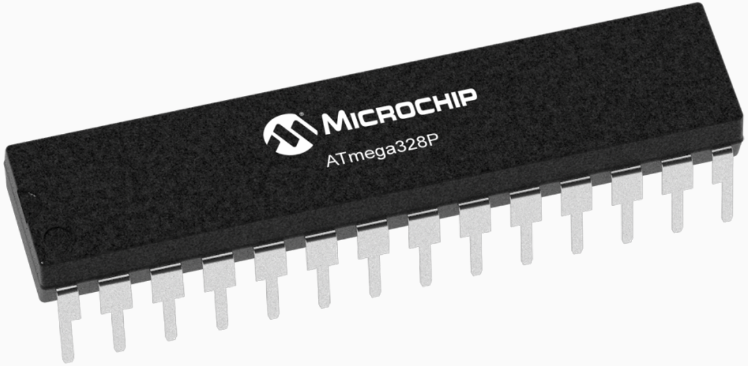
Juan

Juan

Microcontroller Unit (MCU)

ATMEGA328P

- 32 KB of Flash Memory
- 2 KB of SRAM
- 23 Programmable I/O Lines
- Contains 6 Low Power / Sleep Modes: Idle, ADC Noise Reduction, Power-Save, Power-Down, Standby, and Extended Standby.



Juan

Microcontroller Comparison

Microcontroller	Clock Speed	Flash Memory	RAM	Manufacturer	Data Bus Width	Price
MSP430G2553	16 MHz	16 KB	500 B	TI	16-bit	$2.09
ATMEGA328	20 MHz	32 KB	2 KB	AVR	8-bit	$1.90
ATMEGA328P	20 MHz	32 KB	2 KB	AVR	8-bit	$2.08
PIC24F16KA102-I/SP	32 MHz	16 KB	1.5 KB	PIC	16-bit	$2.40
C8051F988	25 MHz	4 KB	512 B	Silicon Labs	8-bit	$1.11

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Accelerometer

ADXL377

- Range of ±200g for measuring
- Bandwidth range of 0.5 Hz to 500 Hz for the three axes.
- Current draw of about 300 µA
- Operates at 1.8 to 3.6 V

Juan

Accelerometer Comparison

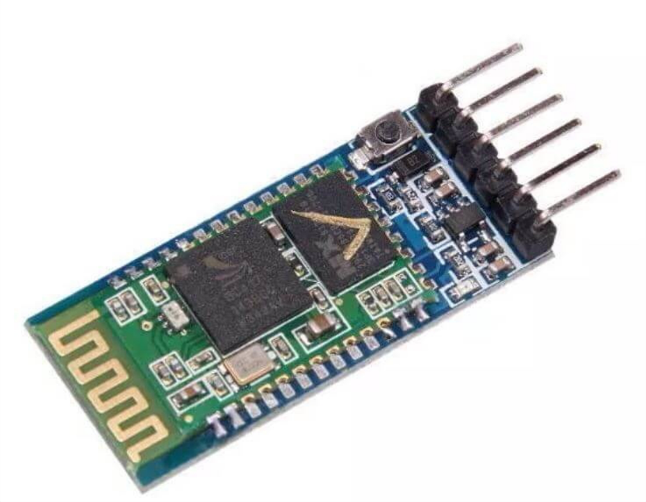
Name	Manufacturer	Bandwidth	Range	Output	Price
ADXL337 3 axis sensor	SparkFun	1500Hz	+3g	I2C	$9.95
ADXL377 3 axis sensor	SparkFun	1500Hz	+200g	I2C	$25.95
LIS2DH 3D Digital Output Motion Sensor	ST Microelectronics	672Hz	+2g-+16g	I2C, SPI	$1.53
LIS3DH 3D Digital Output Motion Sensor	ST Microelectronics	625Hz	+2g-+16g	I2C, SPI (16 bit)	$1.49
MMA8453QT 3-Axis sensor	NXP Semiconductors	0.78Hz-400Hz	+2g-+8g	I2C	$4.00
ADXL327BCPZ 3-Axis low power sensor	Analog Devices	1.6kHz	+2g	Analog	$[illegible]

Juan

Bluetooth Transceiver

HC-05 Bluetooth Module

- Serial Communication (UART)
- Range: 10 Meters
- Transfer Rate: 1 Mbps
- 2.4 GHz frequency band



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Bluetooth Comparison

Name	Manufacturer	Operating Voltage	Current consumption (Transmitting)	Frequency	Price
nRF24L01+	Nordic Semiconductors	1.9 to 3.6V	8.0 to 8.9 mA	2.4 to 2.525GHz	$20.95
RFM69HCW	HopeRF Electronic	1.8 to 3.6V	16 to 130 mA	290 to 1020MHz	$11.95
LS-S100	Lensen	5V	30 to 100 mA	433MHz	$16.00
HC-05	HiLetgo	4 to 6V	30 mA	2.4GHz	$7.99
433MHz RF Link Kit	Seeed	3 to 12V	50 mA	433MHz	$4[illegible]

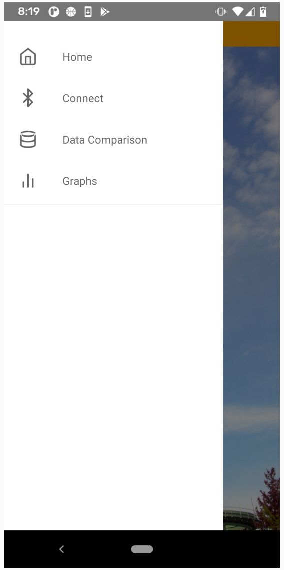
Nick

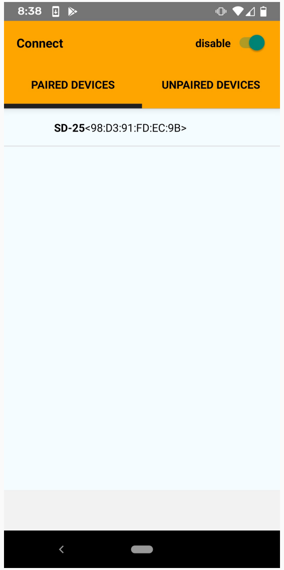
Mobile Application

Android mobile app

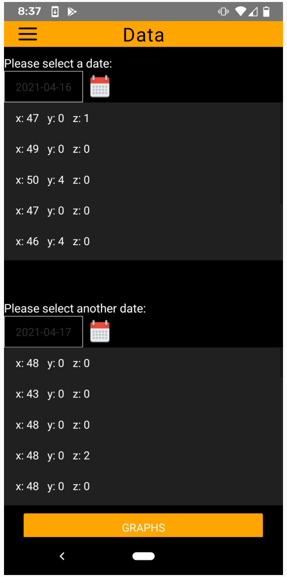
- Programmed using Atom
- Debugged and ran using node.js
- Chose React Native as the mobile application framework
- MongoDB for the database
- Implemented an Android emulator from Android Studios
- Application main function is to receive accelerometer data and display it

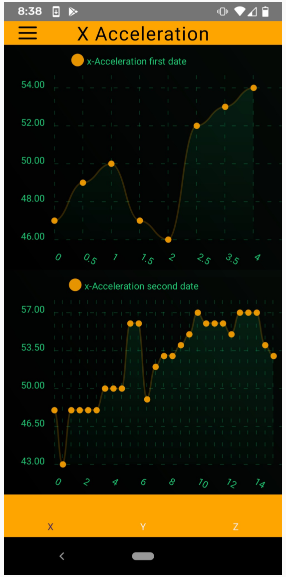
User Interface

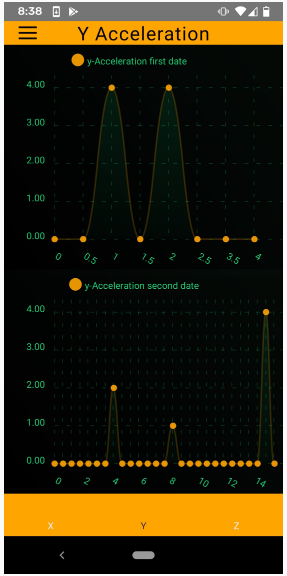


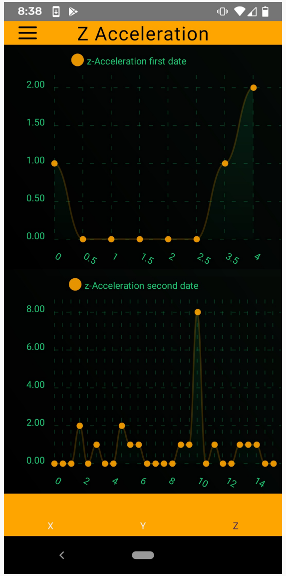


User Interface









Nick

Communication

The Android application will communicate with the MCU via Bluetooth

- Click the switch button which will search for nearby bluetooth devices
- Select the HC-05 bluetooth module from the list
- Will attempt to establish connection
- Once the app displays connected, accelerometer data will be displayed
- Future feature will include a graphical comparison of recorded runs

Phase 2 Successes and Challenges

Nick

Challenges

- Implementing a connection between the mobile app and Bluetooth module

Successes

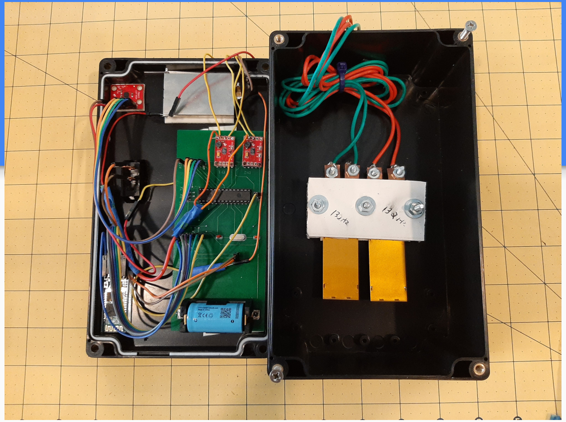
- MCU able to read accelerometer data and display the results through Bluetooth.
- Bluetooth module paired successfully to PC.

Kris

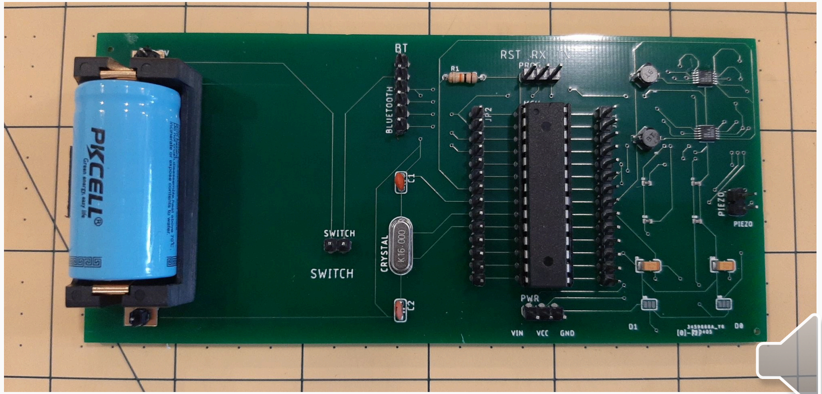
Phase III

Kris

Phase III Obstacles



- Integrated PCB design
  - 3 Weeks remaining
  - Limited Parts Available
- Testing Method
  - No Roller Coasters



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Testing Environment Comparison

Kris

Roller Coaster

Vibration	Motion
✓	✓

Subwoofer

Vibration	Motion
✓	✗

Dynamic Environment

Vibration	Motion
✗	✓

Testing Environment Comparison

Kris

Subwoofer

Vibration	Motion
✓	✗

+

Dynamic Environment

Vibration	Motion
✗	✓

=

Roller Coaster

Vibration	Motion
✓	✓

Phase III Results


Rich

Design Feature	Requirements	Results
Charge	Within 20 minutes	3 minutes 21 seconds
Transmit	Within 1 Minute	26 seconds
Runtime	Greater than 2:30	4 minutes 20 seconds


Rich

Administrative

Budget

Item	Amount	Cost	Total Cost
Piezoelectric Transducers	3	$32	$96
Microcontroller	1	$23	$23
Accelerometer	2	$25	$50
Transceiver	1	$10	$10
BOB Unit	2	$30	$60
Supercapacitor	1	$38	$38
Crystal Oscillator	1	$10	$10
Bluetooth Dev Board	1	$30	$30
Printed Circuit Board (no comp.)	2	varies	$14
Printed Circuit Board (comp.)	1	$70	$70
Enclosure	1	$11	$11
Misc Components*	~	varies	$140
Shipping Costs	~	varies	$162
Approximate Total Cost	~	~	**$714 (Max: $750, $36 under)**

**Misc Components refers to any purchased components that were tested/prototyped but not officially used in final design. It may also refer to smaller components that are not integral to the overall design (wires, headers, etc.)*

Rich

Questions?