LA-UR-17-28526

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Title: 2017 Summer research

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Intended for: Share research with other academic institutions.

Issued: 2017-09-20

2017 Summer Research

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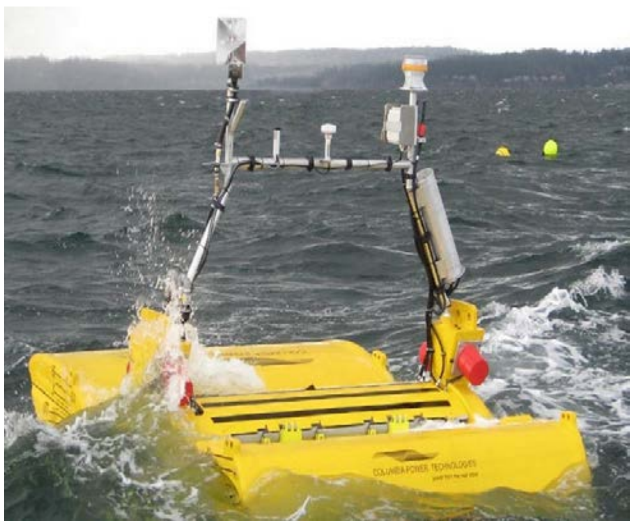
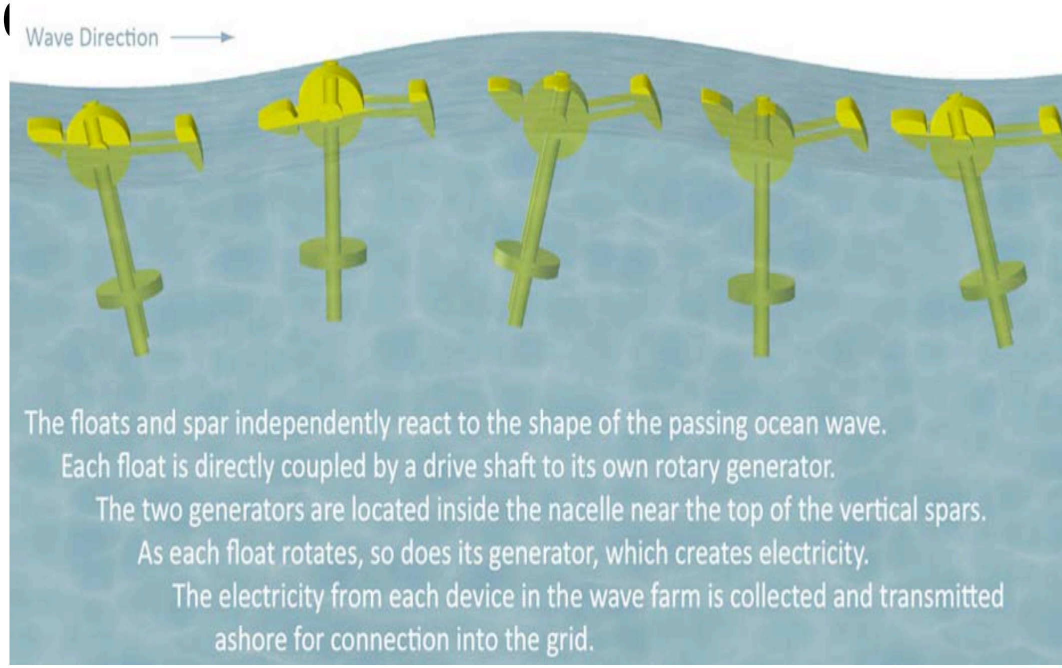
Outline

- WECs introduction
- Impedance measurements gathered through piezoelectric transducers described
- Laboratory measurements performed and algorithms created to analyze data
- Microcontroller experience
- Summary

Wave Energy Converters (WECs)

- Devices harvest energy from ocean waves
- Have the practical ability to account for 12.9% of the annual needs (





Limitations

- One of the biggest problems is money
- Ocean is powerful, corrosive, and hard to monitor
  - High cost for maintenance and evaluation
  - Lack of targeted repair knowledge

Our Proposed Solution

Gather impedance measurements from damaged plates.

Create and implement detection algorithm on MSP432 microcontroller.

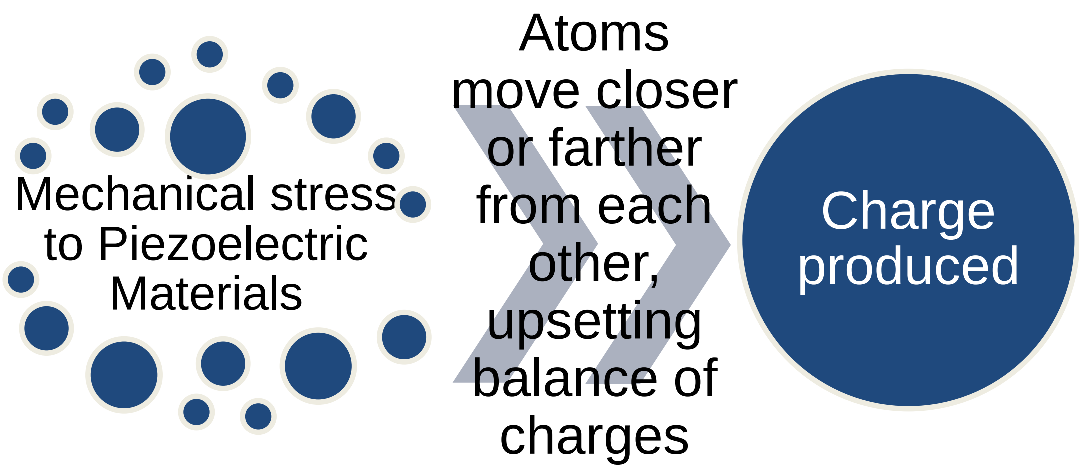
Microcontroller continuously analyzes data aboard WECs looking for abnormalities.

Damage is found; repair crew is alerted.

Damage is triaged and mitigated accordingly.

Data Collection

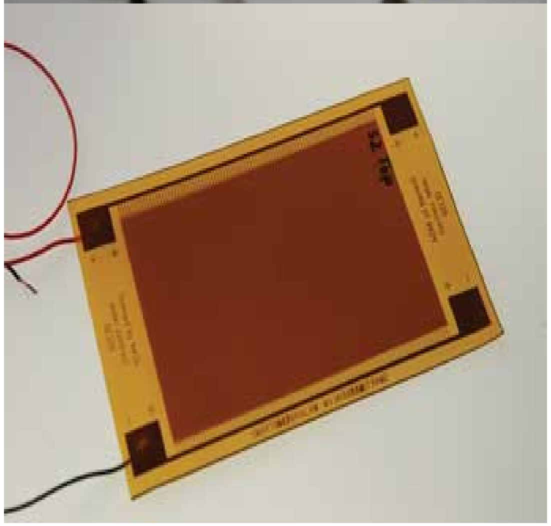
- Relies on the piezoelectric effect to gather impedance measurements from transducers on composite plates

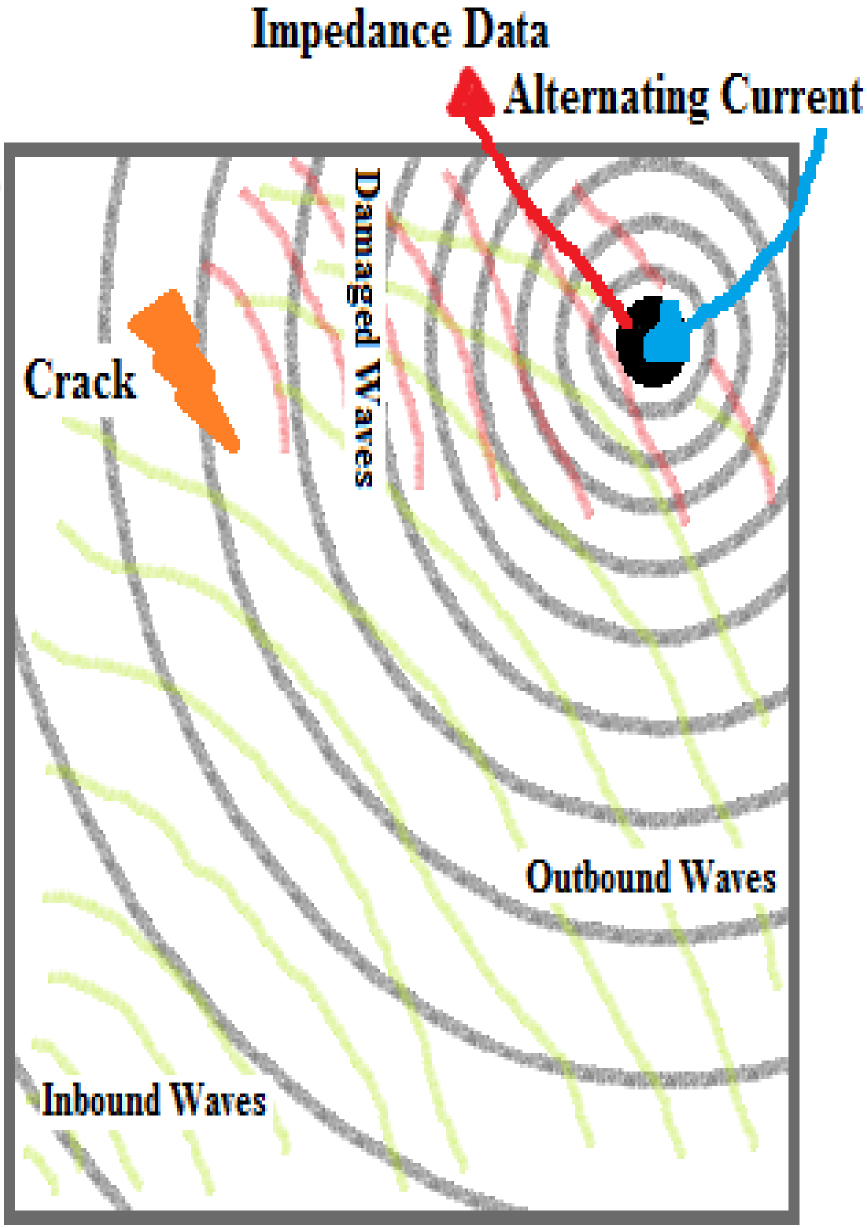


Data Collection (Cont.)

- Macro Fiber Composite (MFC) and American Piezo Ceramics (APC) transducers acting as actuators and sensors nearly simultaneously

- An alternating current sent to transducers and corresponds to frequency of excitation; waves travel through the material and returning waves generate a charge from transducers





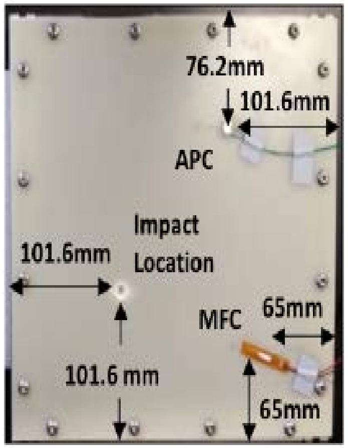
- Transducer gets excited, waves propagate through material
- Bounce around and return to transducer.
- Provides mechanical stress to transducer and charge is produced

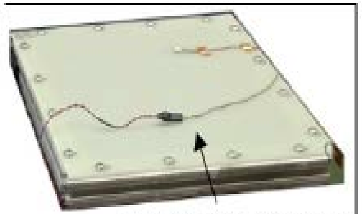
Z=E/I

Z=Impedance
E=Voltage
I=Current

Data Analysis

- Impedance measurements from replicated damage are run through algorithm (created in MATLAB) that uses several statistical methods to analyze data
- Seemingly disordered data reveals general trends as damage levels increase
- We can use these trends to quantify not only whether damage is present, but the extent of damage



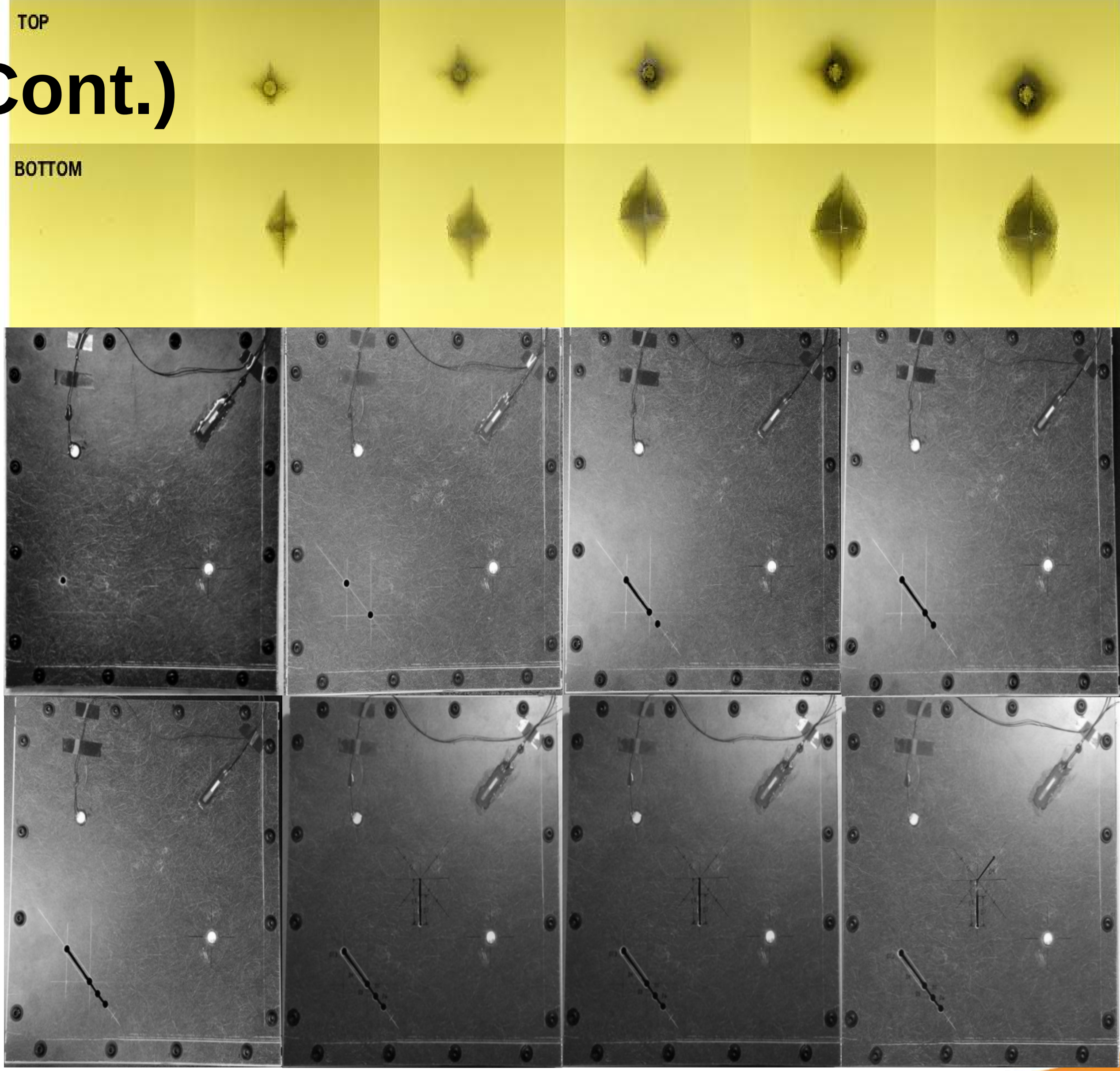


Instrumented test plate
with aluminum support frame

Drop test stand used to impact composite plates to introduce penetration damage and delamination within the laminate

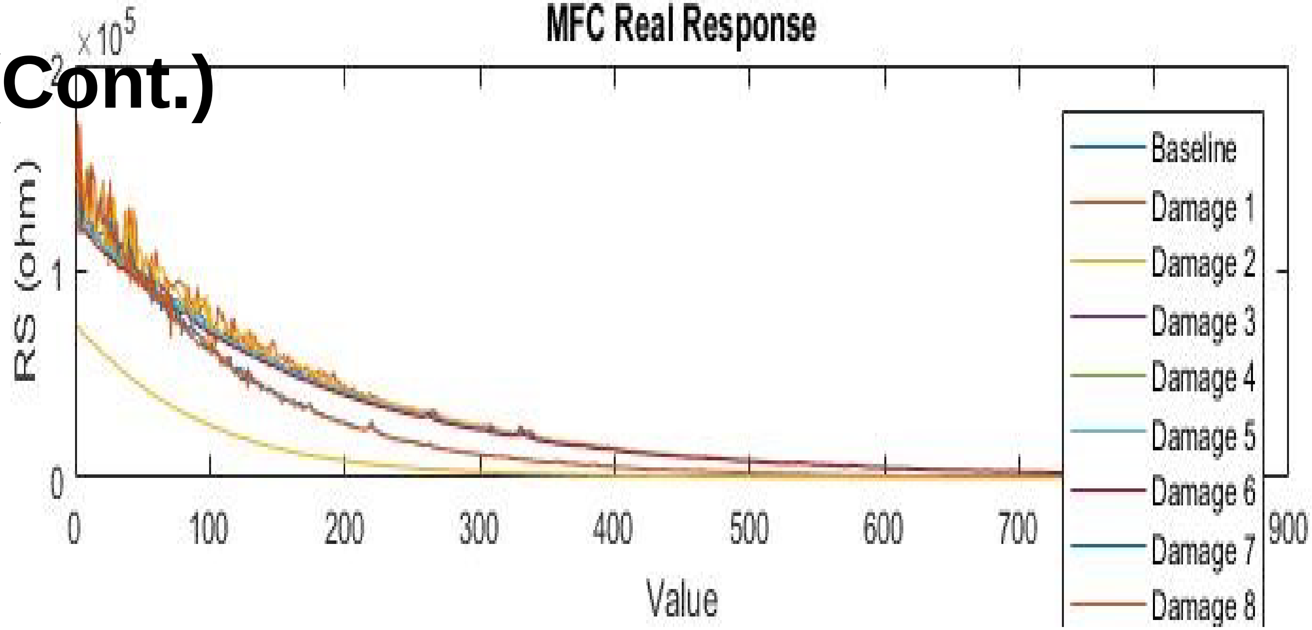
Data Analysis (Cont.)

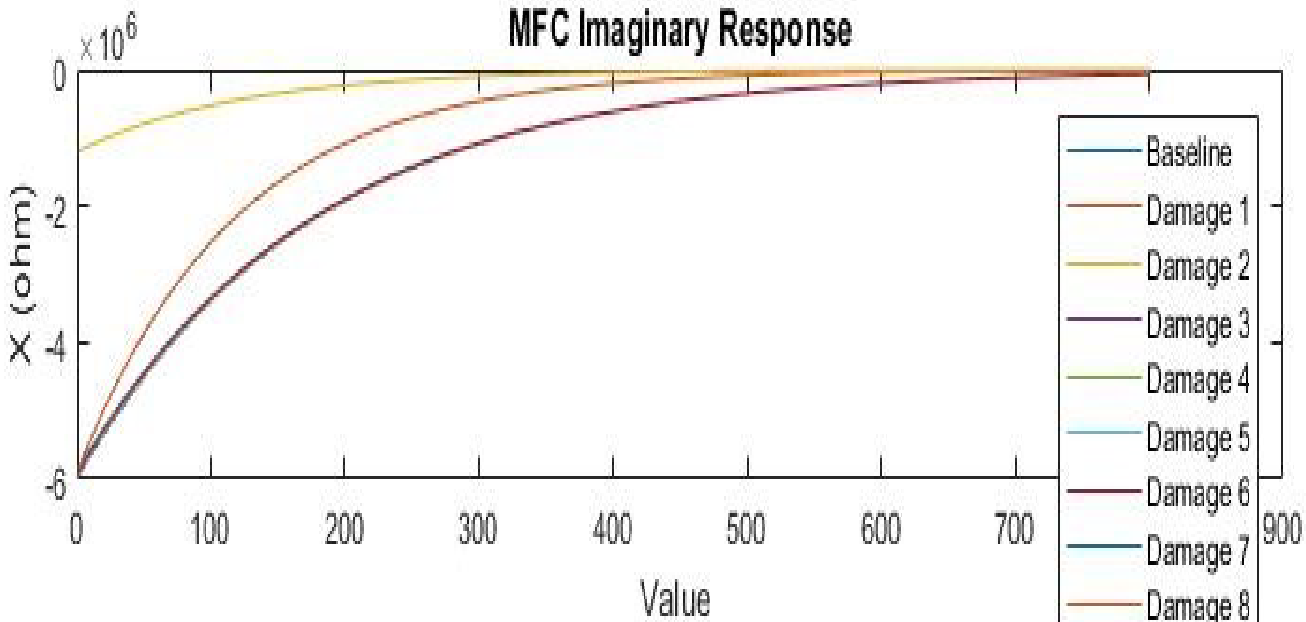
- Measurements were gathered from two different types of simulated damage at different levels: impact from a drop test (top yellow photos) and precise holes/slit from a drill (bottom dark photos)



Data Analysis (Cont.)

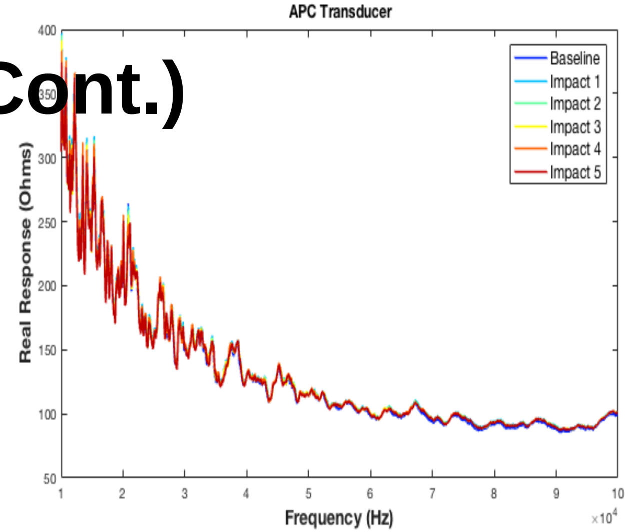
- The real and imaginary response of MFC impedance measurements from hole/slot plates are plotted to a value corresponding to time
- No obvious trends as damage level increases
- Plotting done through MATLAB

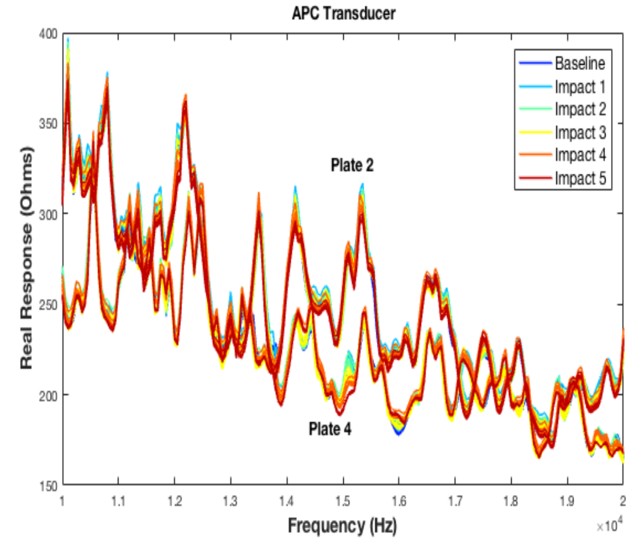


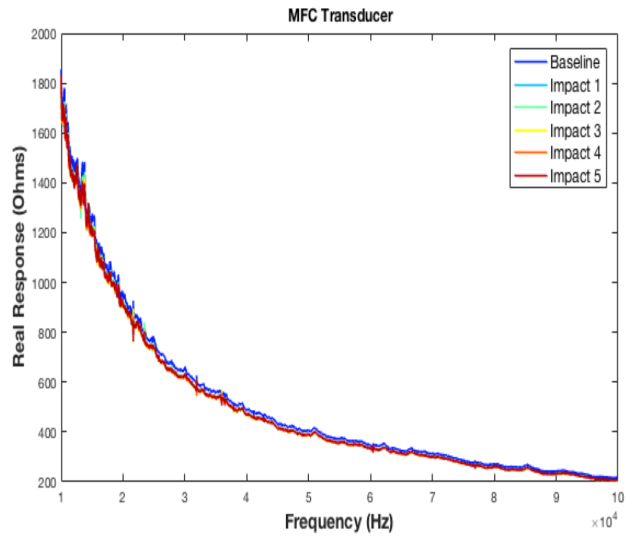


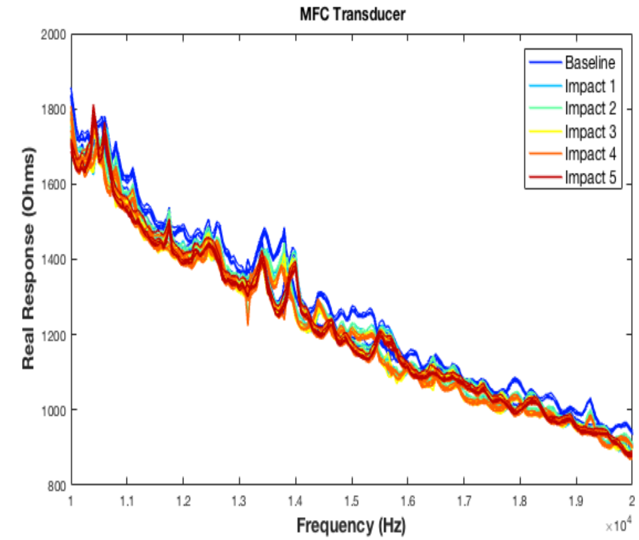
Data Analysis (Cont.)

- The real and imaginary response of MFC and APC impedance measurements from the impact test plates are plotted vs. the frequency of excitation
- Right graphs are zoomed in window of left graphs
- No obvious emergent trend
- Plotting done through MATLAB



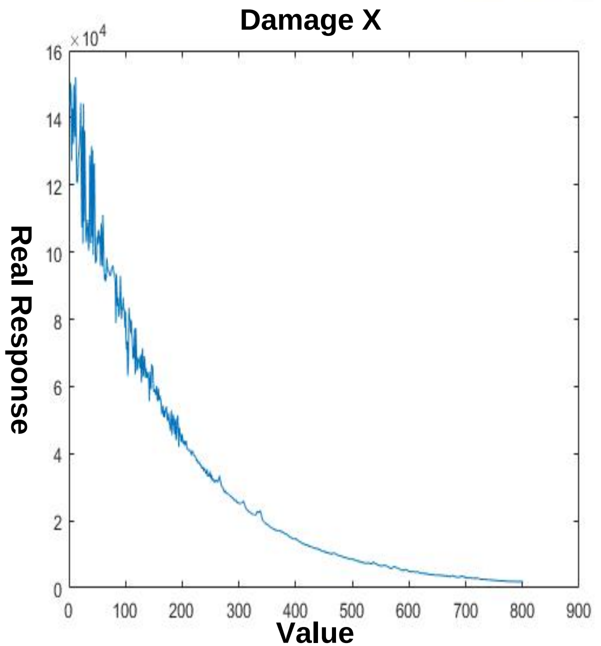


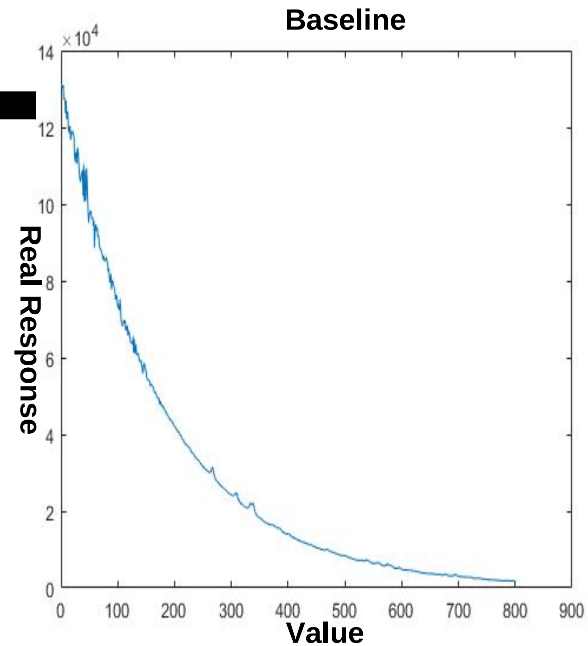


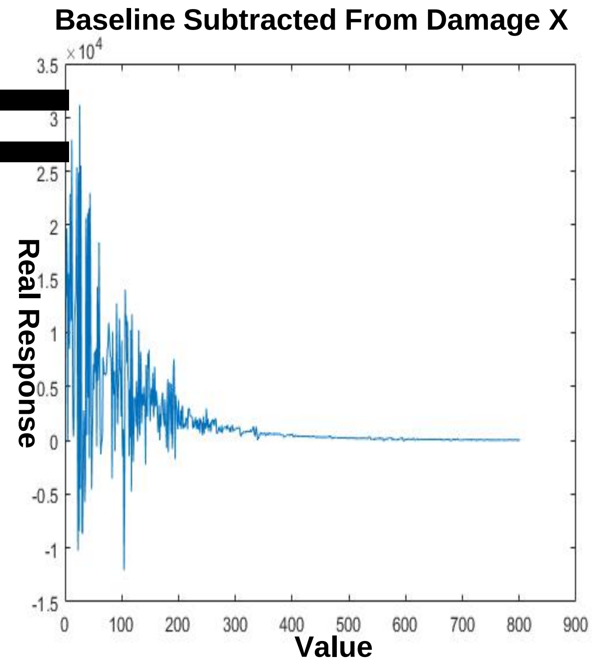


Data Analysis (Cont.)

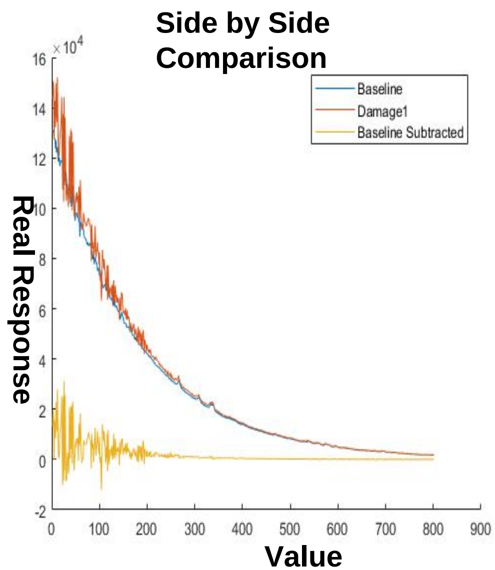
1. Subtract the baseline values from each damage level
2. Analyze subtracted values by testing:
   - Orthogonality
   - Standard Deviation
   - Peak Amplitude
   - Mean Squared
   - Variance
   - Root Mean Squared
   - Mean Amplitude
   - Mahalanobis Distance (with multiple baseline measurements)



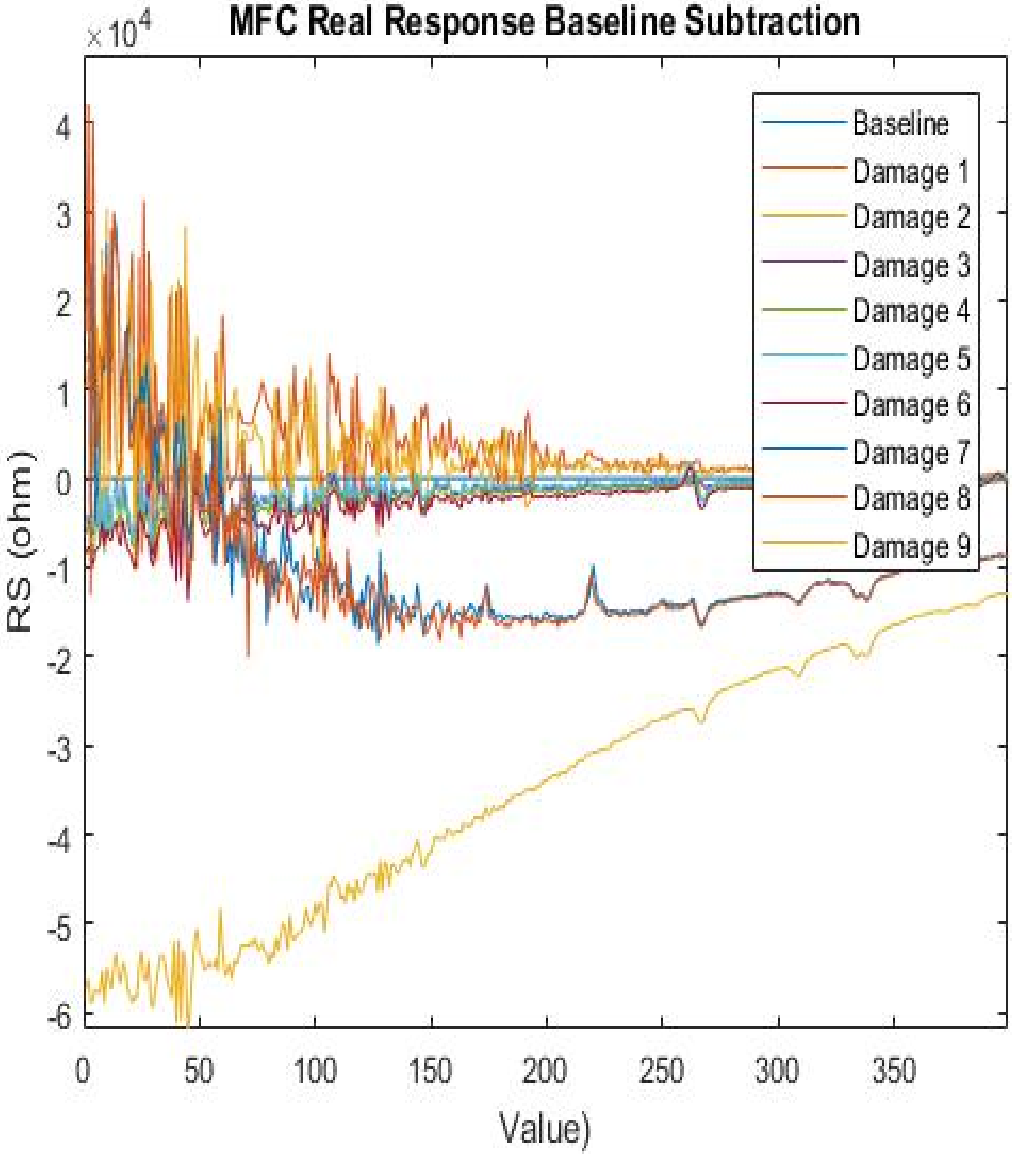




- Baseline subtraction better reveals minute differences between nearly parallel lines



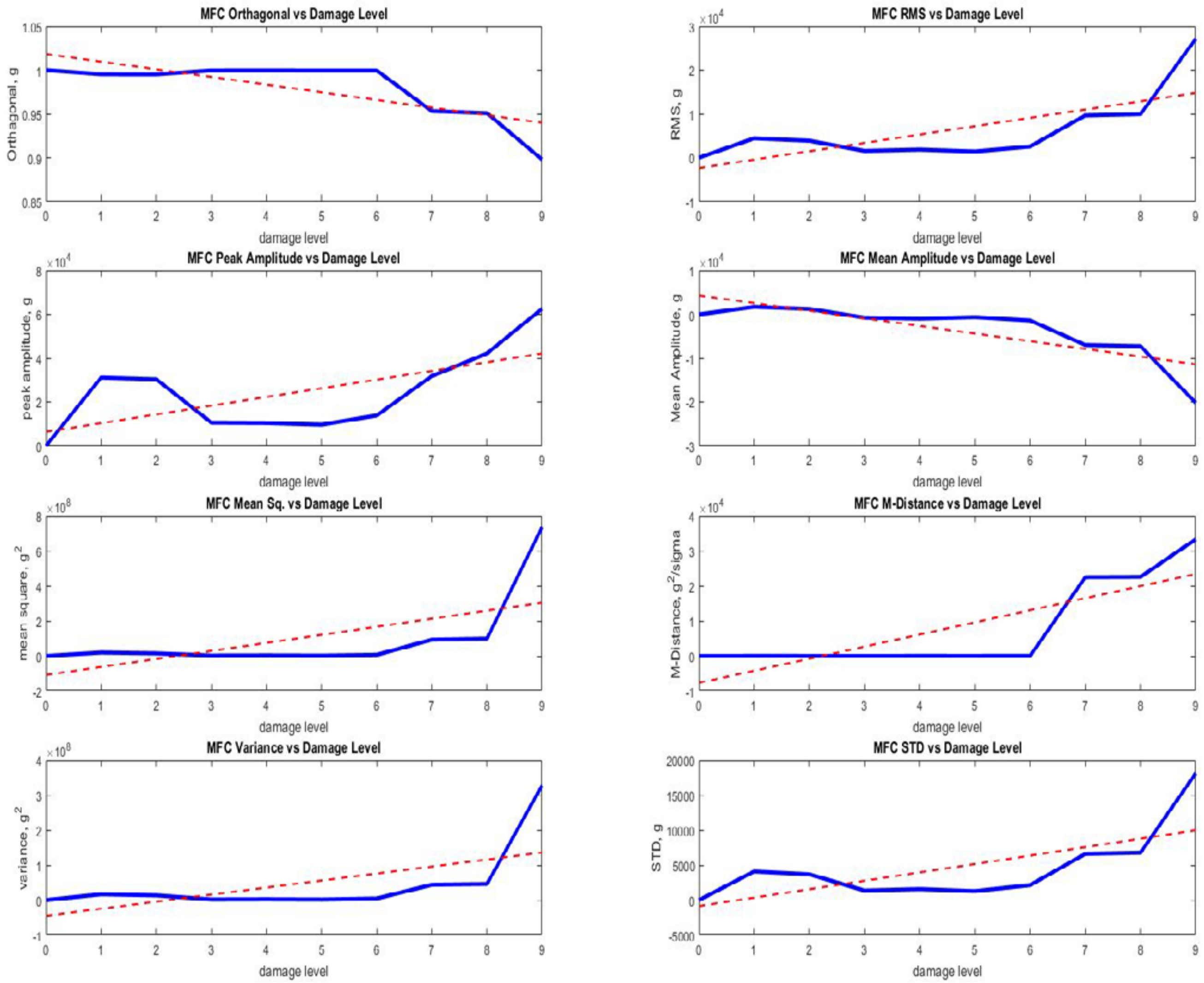
- Plot of all damage levels with the baseline subtracted from them
- Still no obvious trend, but distinguishable differences



Name	Equation	Description
Orthogonality	$DM_{ORTH}=\frac{\lvert\{y_u\}^T\{y_d^*\}\rvert^2}{(\{y_u\}^T\{y_u^*\})(\{y_d\}^T\{y_d^*\})}$	Measures how orthogonal or how parallel (0-1) the data is.
Standard Deviation	$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$	Used to quantify the amount of variation of a set of data
Variance	$Var=\sigma^2$	Used to measure how far values are spread out from their average value
Mean Square	Mean Square = $\frac{1}{N}\sum_{i=1}^{N}(x_i)^2$	Used to measure difference between the baseline and damaged cases
Root Mean Square	$RMS=\sqrt{Mean\ Square}$	Used to measure difference between the baseline and damaged cases
Mahalanobis Distance	M-Distance=$\frac{Mean\ Square}{\sigma^2}$	Used to measure difference between the baseline and damaged cases but adjusted to weigh certain values differently based on the normal variance between baseline measurements

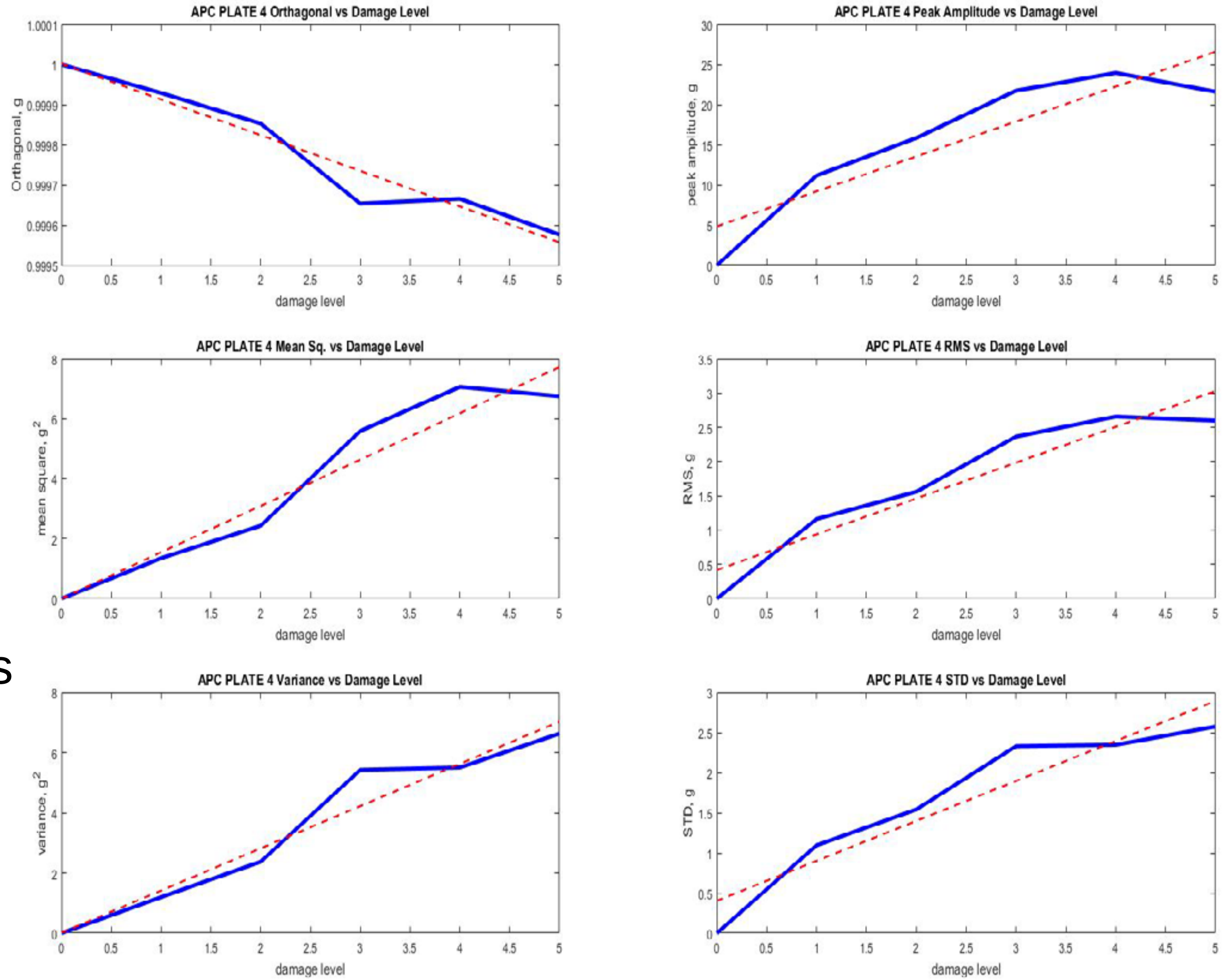
Sample Hole and Slot Analysis

- Data from MFC hole/slot damage
- Doesn't fit perfectly, but definite evidence of emergent trends
- Solid blue line is a plot of the values, the dashed red line is a best fit line



Sample Impact Analysis

- Data from APC impact test
- Very obvious emergent trends in the data; as damage increases, the resulting values of statistical processing methods is predictable
- Solid blue line is a plot of the values; the dashed red line is a best fit line



Remote detection

- Next step is to implement algorithm onto microcontroller
  - TI-MSP432P4014 low-power high-precision microcontroller; comes with tradeoffs
    - Difficult to turn MATLAB function into C
    - Difficult to program
- Theoretically, microcontroller will continuously analyze incoming impedance measurements from composite plates and detect the damage on the WEC; send signal to maintenance crew

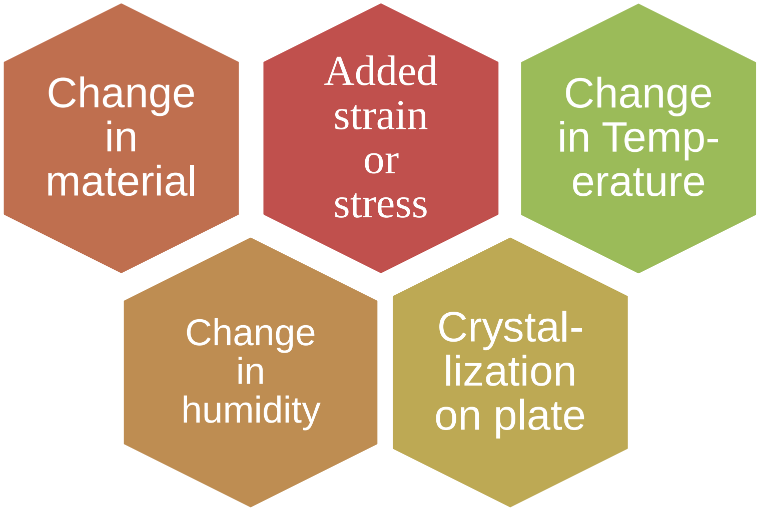
Microcontroller Successes

- Found usable GUI, obtained drivers, interfaced with microcontroller
- Was able to write and run code, and control input/output pins
- Used MATLAB Coder to generate usable C code function and implemented on microcontroller
- Was able to use variance to determine whether array was close to the baseline value or not, and blink a corresponding LED

Challenges

- LANL proxy
- Minimal outside resources for MSP432
- Piezoelectric materials are VERY sensitive

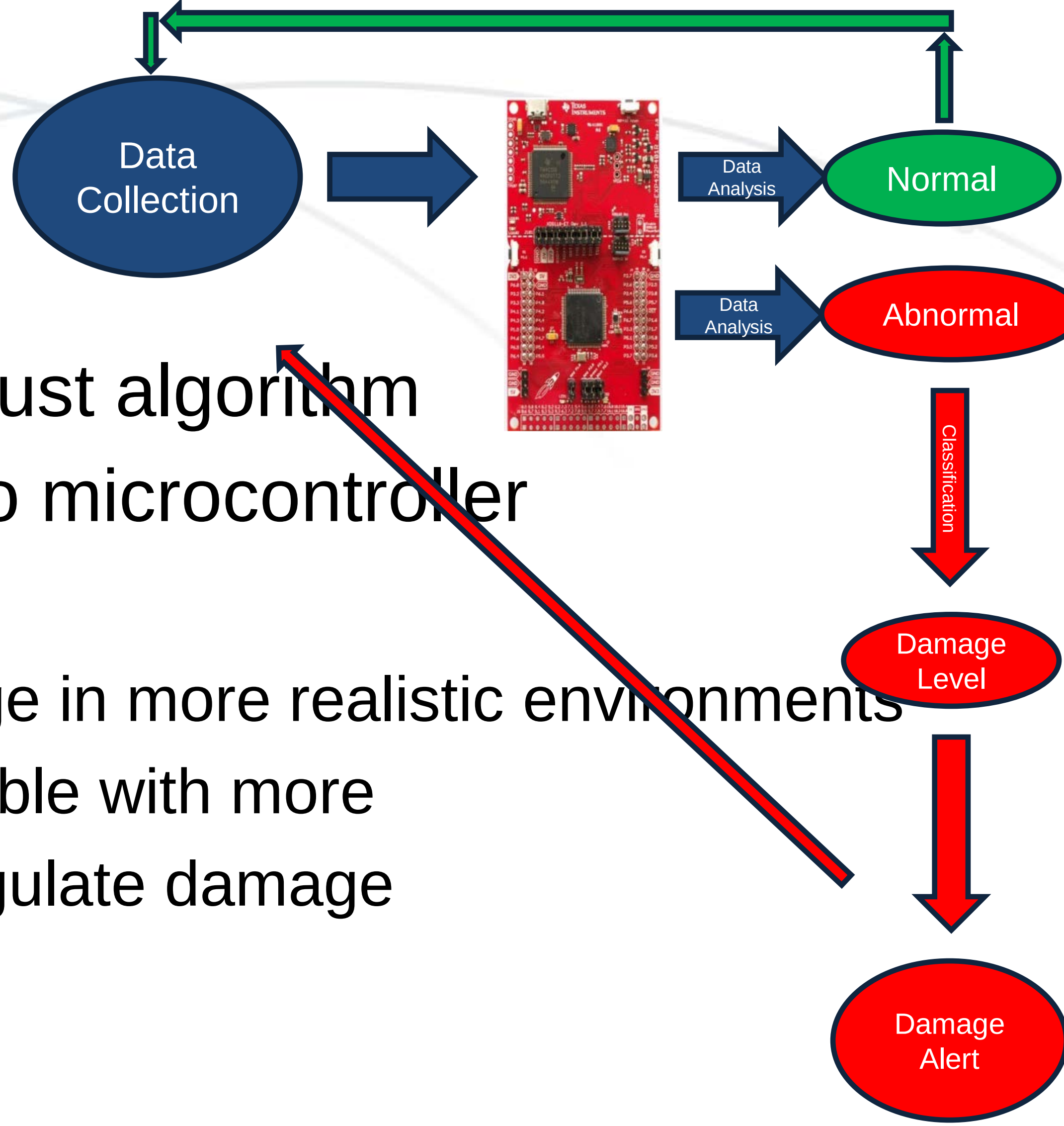
Change in impedance measurements can result from a variety of events:



Conclusions

- As damage increases, statistically significant changes in impedance measurements occur which correspond to damage level
- Trends can be used to detect if damage is present and the extent of damage

Moving Forward



- Finalize a more robust algorithm
- Fully implement into microcontroller
- Future work:
  - Test different damage in more realistic environments
  - Adapt to be compatible with more transducers to triangulate damage as well

Implications

- Assuming success, our work could lower cost of WECs
- Usage of piezoelectric damage detection furthered to a higher variety of applications

Summary

- WECs are a promising opportunity for renewable energy, but still not feasible; by directing maintenance, we can lower costs
- Impedance measurements gathered through piezoelectric transducers can tell us if data are damaged and the extent of damage
- Further work needed to make a more robust algorithm to be adapted onto microcontroller