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http://wang.ce.gatech.edu School of Civil and Environmental Engineering

Autonomous Ultrasonic Thickness Measurement of Steel Bridge Members Using Mobile Sensors

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INSPIRE University Transportation Center
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INSPIRE UTC Annual Meeting
August 3, 2018

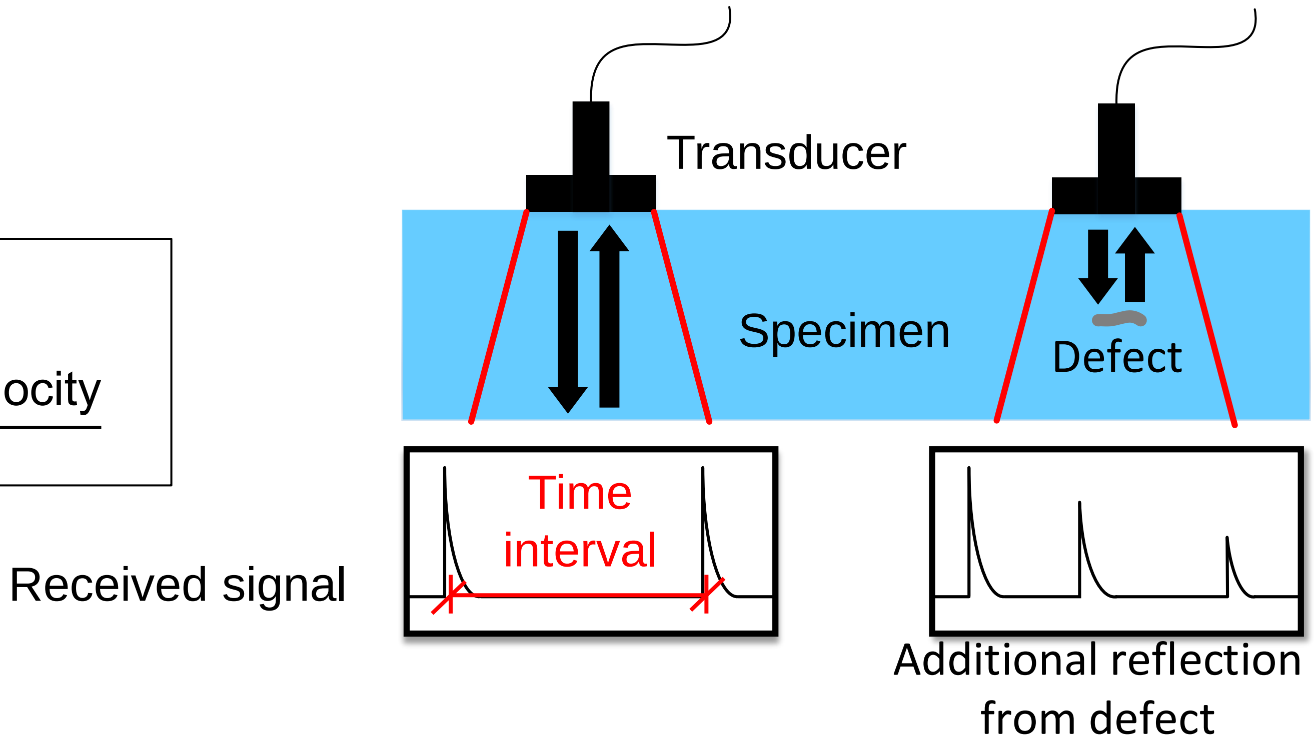
Outline

- Introduction
- Initial Investigation of Autonomous Ultrasonic Thickness Measurement
  - *Martlet* Ultrasonic Board
  - Transducer and Couplant
  - Magnet-Wheeled Mobile Robot
- Hardware Improvement
  - 300V Pulser Board
  - Transducer Selection
  - New Ultrasonic ADC Board
- Conclusion and Future Work

Ultrasonic Thickness Measurement

- Ultrasonic signal (500kHz – 50MHz for NDE) generated and received by a transducer
- Only requires access to one side of a specimen
- Thickness and defect detection of steel members in a bridge

$$\text{Thickness} = \frac{\text{Time interval} \times \text{Velocity}}{2}$$



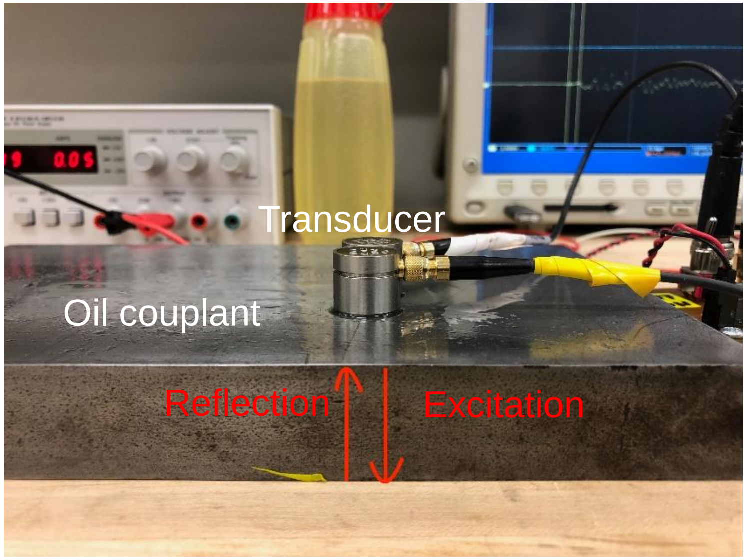
Components

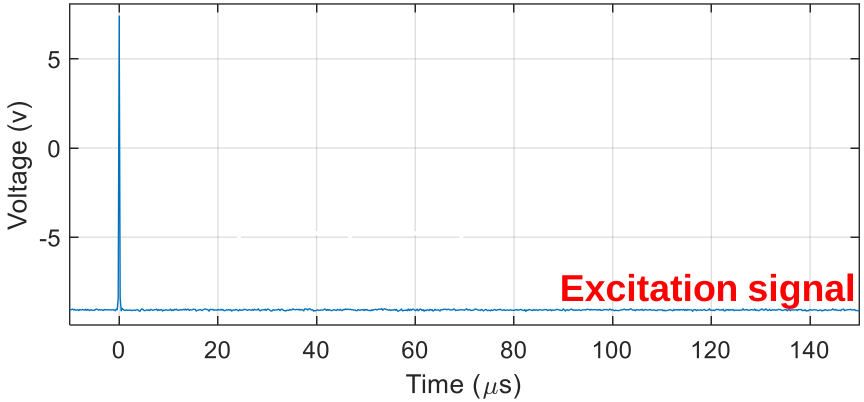
Transducer

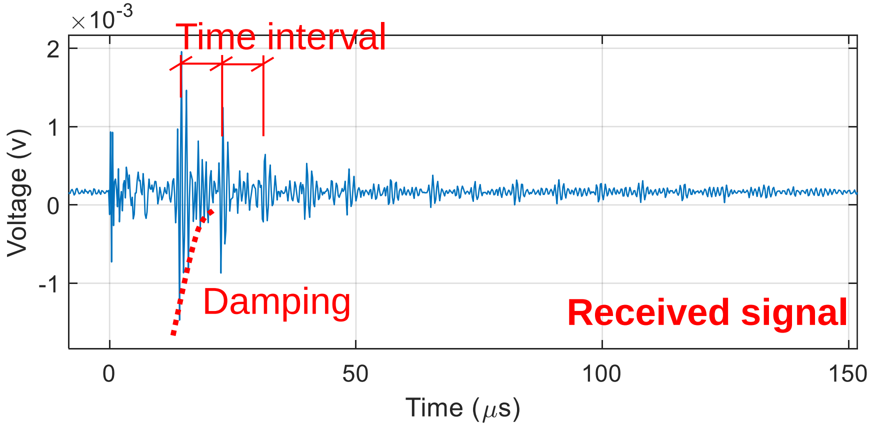
- Generate/receive ultrasonic signal by the piezoelectric effect

Couplant

- Material that facilitates the transmission of ultrasonic signal from the transducer into the test specimen, e.g. oil, water, elastomer couplant

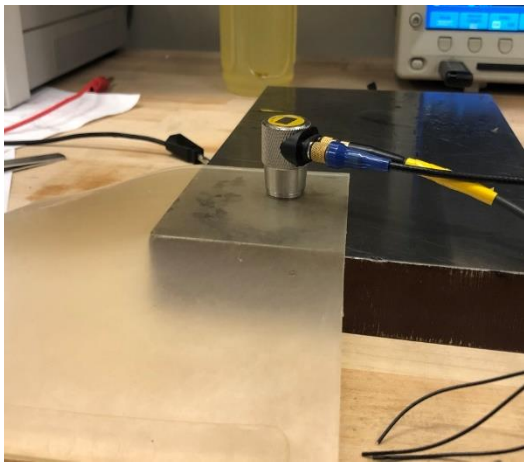


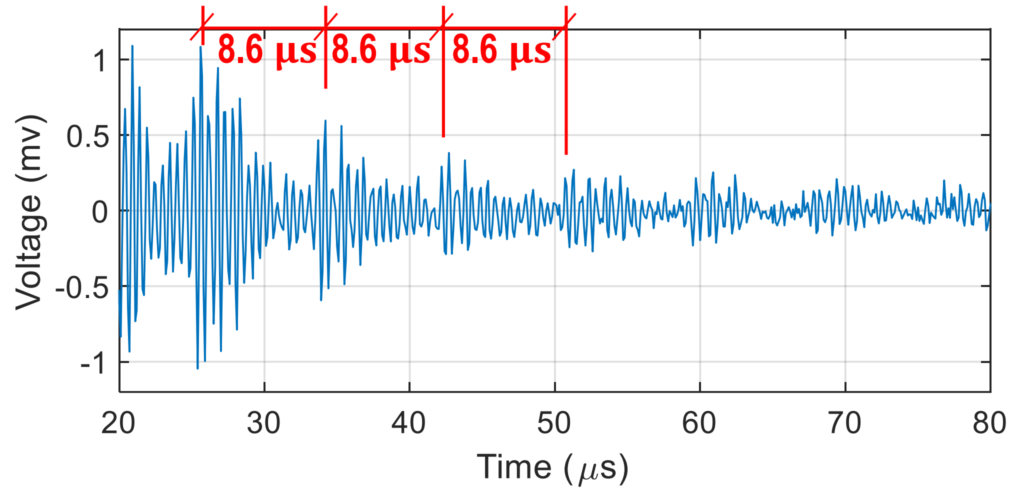




Laboratory Test

- Thickness measurement of a 1” thick steel plate
- Impulse excitation generated by a 1MHz dual-element transducer
- Data acquisition by oscilloscope (1.25 GHz sampling rate)
- Ultrasonic wave velocity 0.230 in/μs (13,068 mph)





$$\text{Thickness} = \frac{\text{Time interval} \times \text{Velocity}}{2} = \frac{8.6\ \mu s \times 0.230\ \text{in}/\mu s}{2} = 0.99\ \text{in}$$

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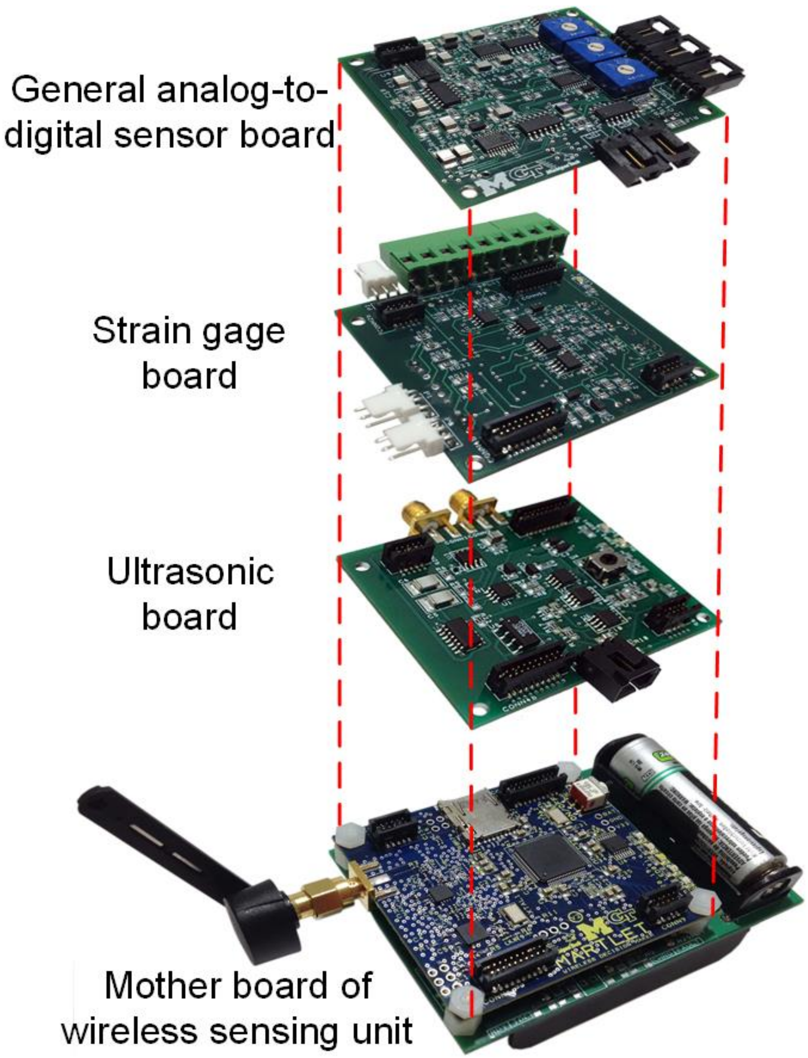
  - ➢ New ultrasonic ADC board
- ❑ Conclusion and Future Work

Martlet Wireless Sensing



- General ADC/DAC board
  - ADC: On-the-fly programmable gain and cutoff frequency
  - DAC: output voltage 0 – 3.3V
- Strain board
  - Optional ranges: ±2,000/10,000 με
  - Noise floor: 1-2 με
  - 120Ω or 350Ω gages
- Ultrasonic board
  - Generate up to 500 kHz excitation
  - Sample rate up to 3 MHz

***Martlet* Features**	
Computing power	90 MHz – FPU Dual-core
Line-of-sight comm.	800 meters
Max. sampling rate	3 MHz
Analog-to-digital converter	9 Channels 12-bit

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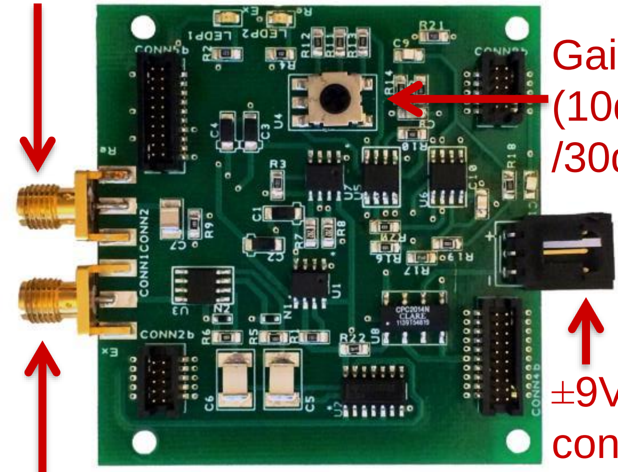
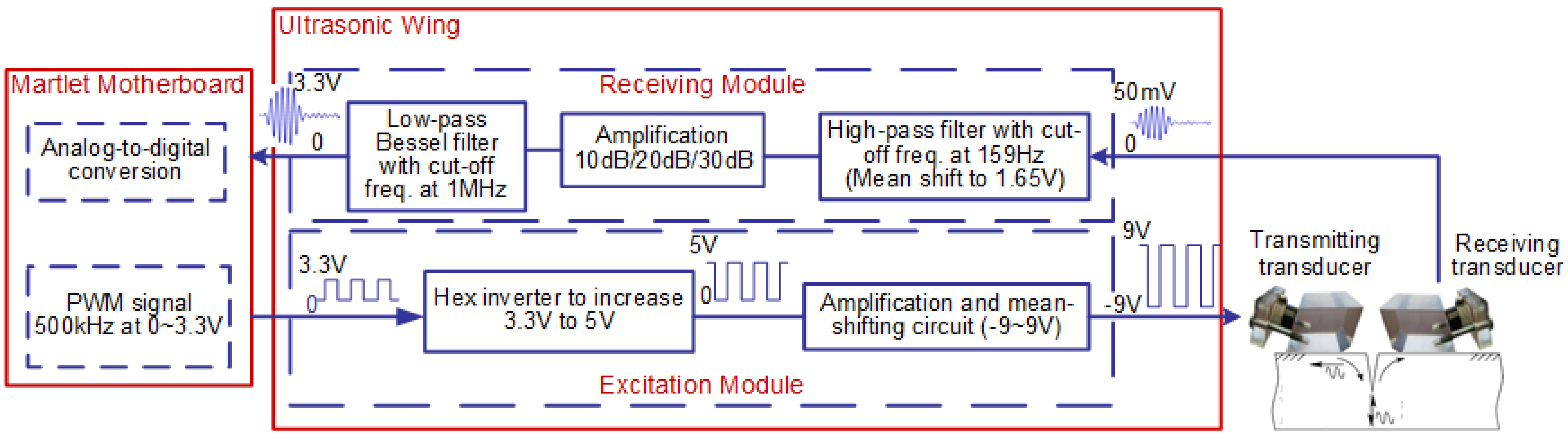
Martlet Ultrasonic Board

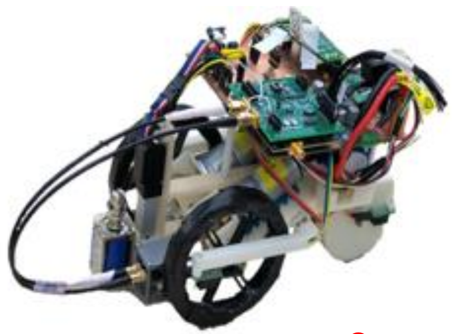
- Pitch-catch setup for launching Rayleigh wave to detect surface crack
- Excitation module amplifies PWM signals for transmitting transducer
- Receiving module provides anti-aliasing filtering and selectable amplification gains (10/20/30 dB)





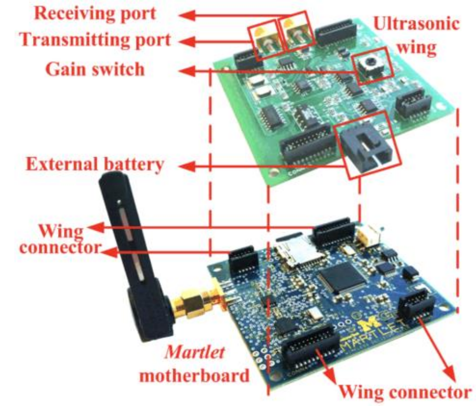
Development of Autonomous Ultrasonic Thickness Measurement System

Magnet-Wheeled Mobile Robot



Transducer & Elastomer Couplant

Martlet Ultrasonic Board



Wireless data collection

Base station

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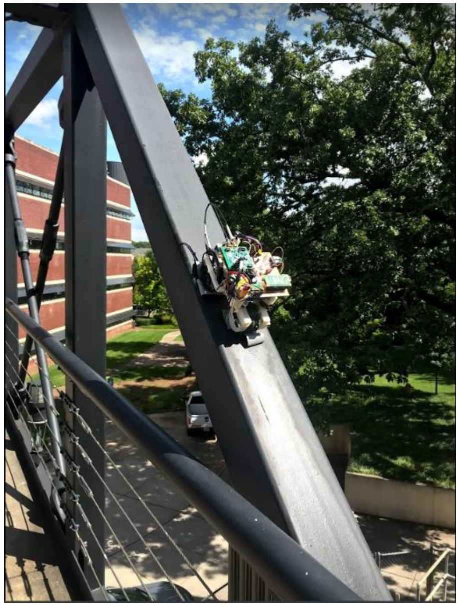
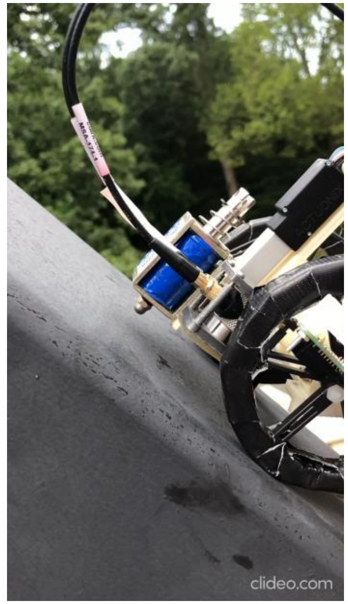
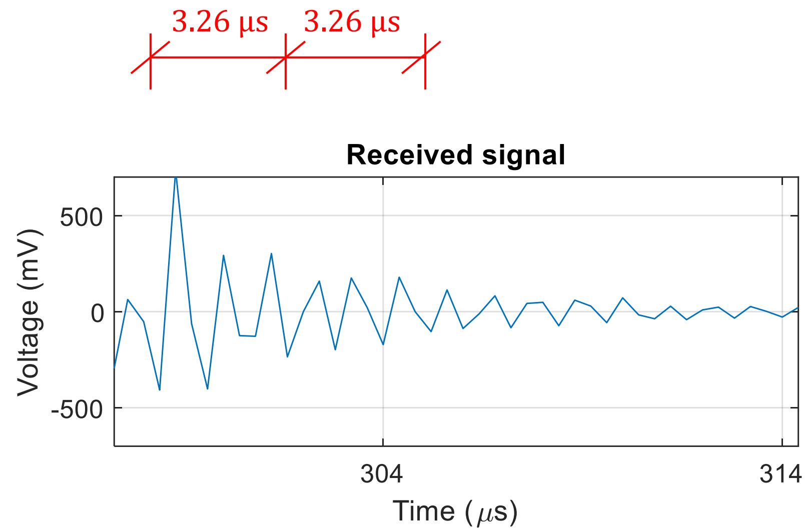
Field Test on Steel Pedestrian Bridge at GT Campus







- *Martlet* wireless ultrasonic board was changed to provide an impulse excitation of 200 ns duration at ±20V
- The wireless ultrasonic thickness measurement setup is successfully operated by the mobile robot and the received signal is wirelessly collected
- However the ultrasonic signal is not able to provide accurate thickness of 0.375 in (round-trip 3.26μs); future development is expected to improve the accuracy

Diagnosis and Plan for Improvement

Possible causes for the difficulty in field testing:

- Excitation amplitude was too small, which resulted in low signal-to-noise ratio
- Elastomer couplant requires high pressure that is not desirable
- The 1MHz transducer has low-damping circuit and the excitation frequency is relatively low; both may have reduced the measurement resolution
- Sampling rate of *Martlet* is 3MHz, which could be increased to better capture the waveform

Preliminary studies lead to the following research directions:

- Increase the pulse excitation voltage
- Investigate different types of couplants
- Investigate transducers with higher-damping and higher excitation frequency
- Increase the sampling rate

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Hardware Improvement

1MHz dual element transducer

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Elastomer couplant

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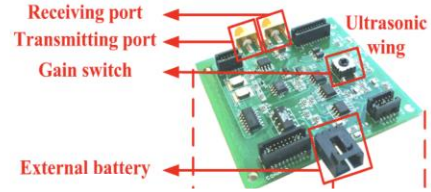
Ultrasonic board



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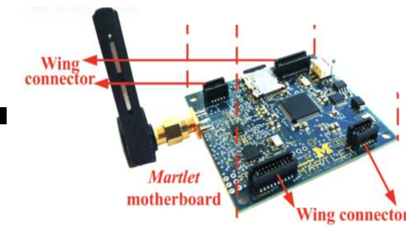
Martlet



Martlet supports up to 3MHz on board sampling rate

Previous approach

2.25MHz dual element transducer

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Water as couplant

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300-Volt Pulser board

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Ultrasonic ADC board

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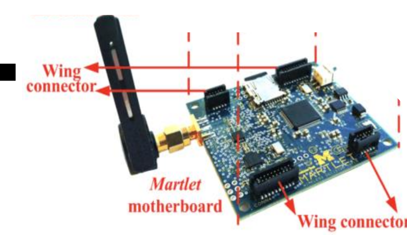
Martlet



Increase sampling rate using an external ADC chip

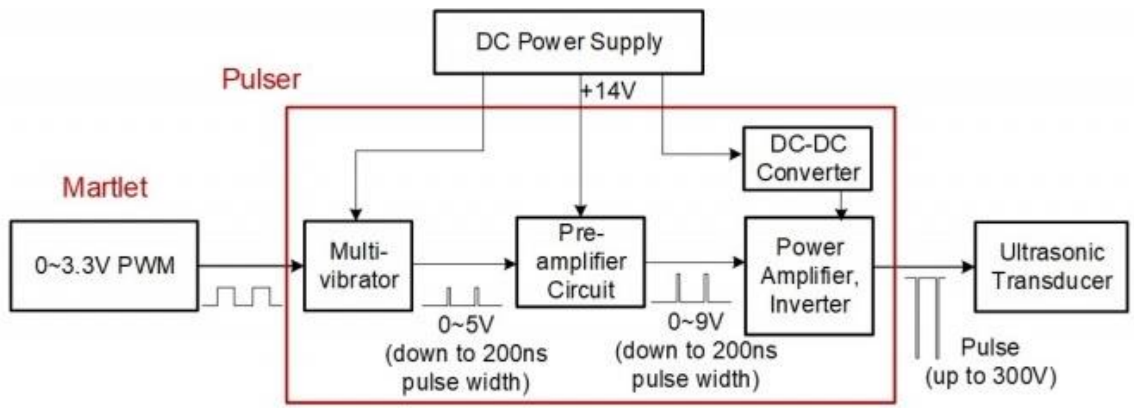
Current approach

300V Pulser Board

- Amplifies the amplitude of the excitation signal from *Martlet* up to 300V
- Adjusts the pulse width down to 200 ns to achieve nearly ideal pulse excitation
- Only requires ~14V power supply

300V Pulser board
(4 inch x 2.4 inch)

Schematic



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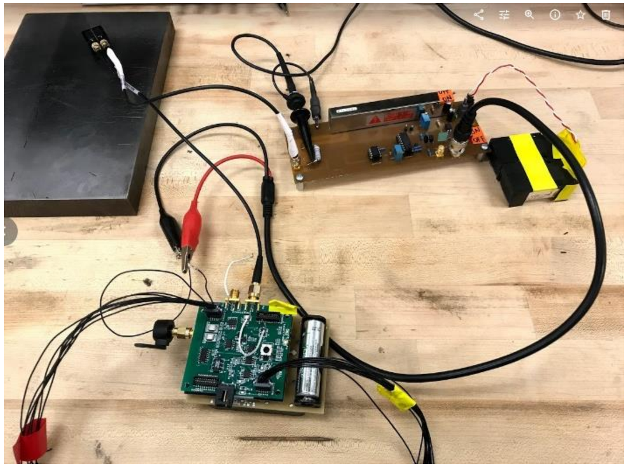
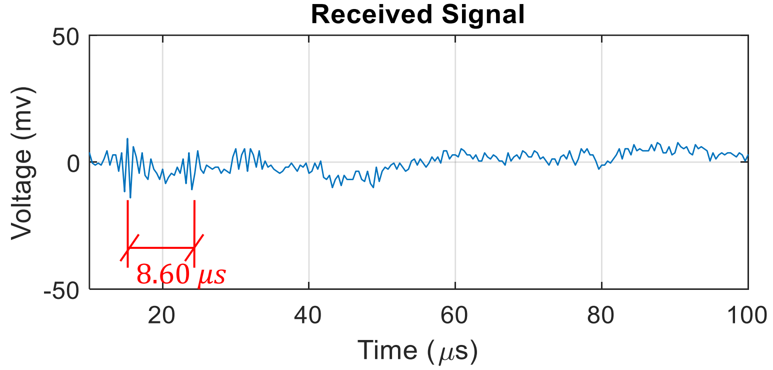
Comparison with/without 300V Pulser Board

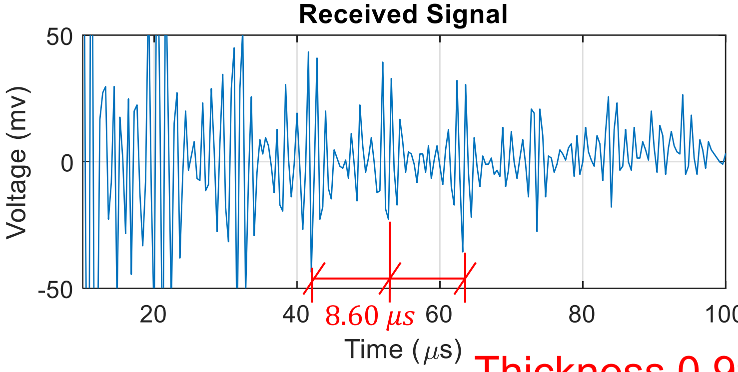
- 1'' steel plate
- 1MHz dual element transducer
- Oil couplant
- Sampled by *Martlet* at 3MHz



Without pulser board (+/-9V square wave by previous ultrasonic board)



With pulser board (100V pulse)



Thickness 0.99” at 0.23 in/μs velocity

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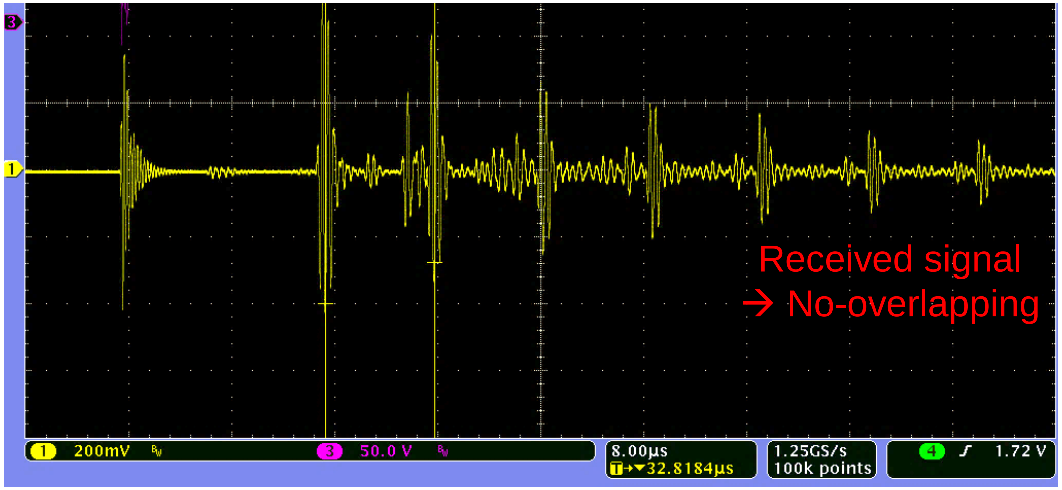
2.25MHz Dual Element Transducer

- 2.25MHz natural frequency→ Higher resolution than the previous 1MHz frequency
- Higher damping circuit → Prevent overlapping of received wave groups; clear separation is observed
- Higher gain by the internal circuit → Better signal-to-noise ratio

2.25MHz dual element transducer
(Baker Hughes Inc.)



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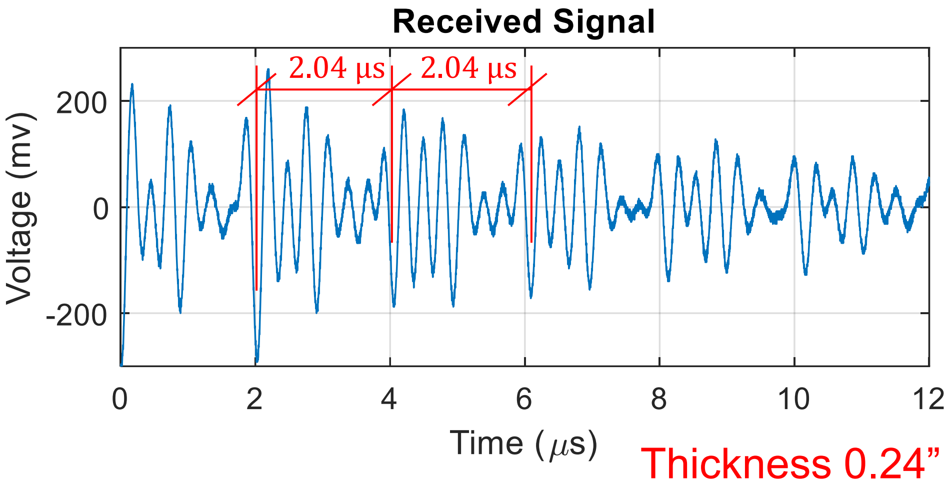
Pulser Board with 2.25MHz Dual Element Transducer & Water



Thickness 0.24” at 0.23 in/µs velocity

Test setup

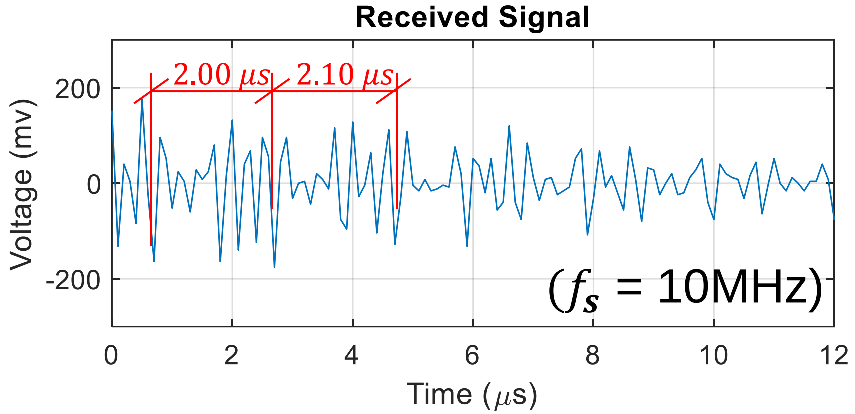
- 0.25’’ rusty steel
- 300V pulse excitation
- 2.25MHz dual element transducer
- Water couplant
- Sampled by oscilloscope (f_s = 2.5GHz)

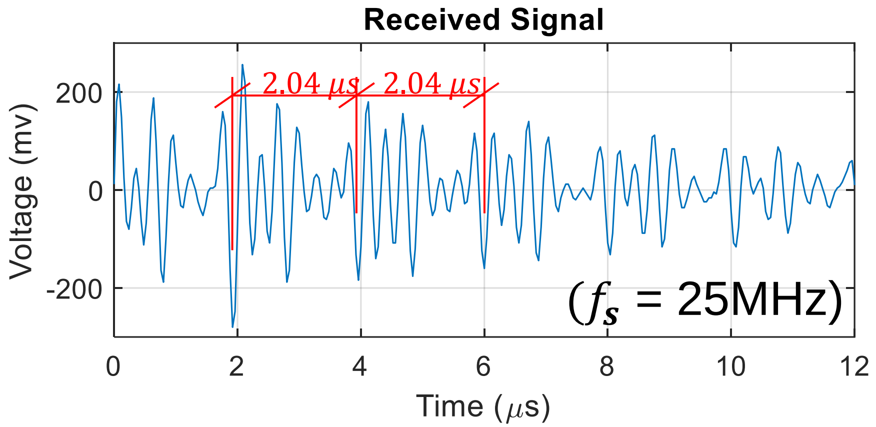
Results

- With the pulser board and new transducer, the amplitude of the received signal is greatly increased.
- Water couplant works nearly as well as oil couplant
- The system works well on a thin rusty steel member

Required Sampling Rate for 2.25MHz Transducer

- Down-sample the received signal to see the effect of different sampling rates





Sampling rate	f_s = 10MHz	f_s = 25MHz	f_s = 50MHz	f_s = 2.5GHz
Sampling period ($= \frac{1}{f_s}$)	0.10 μs	0.04 μs	0.02 μs	0.0004μs
First two peak-to-peak time intervals	2.00 μs 2.10 μs	2.04 μs 2.04 μs	2.04 μs 2.04 μs	2.04 μs 2.04 μs

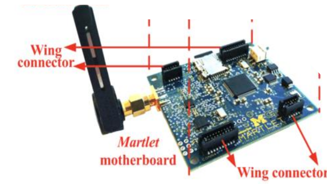
- A minimum of 25 MHz sampling rate is preferred

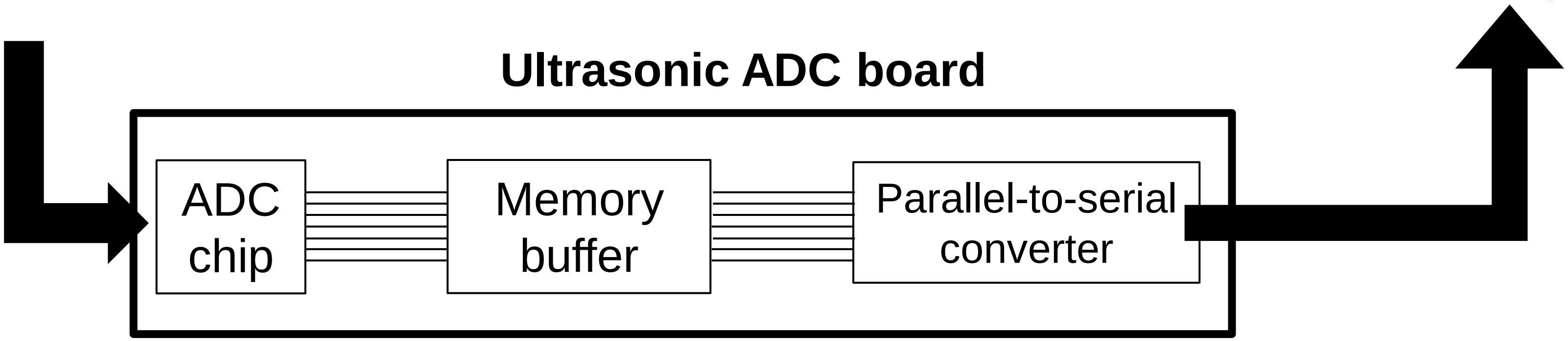
Development of a New Ultrasonic ADC Board

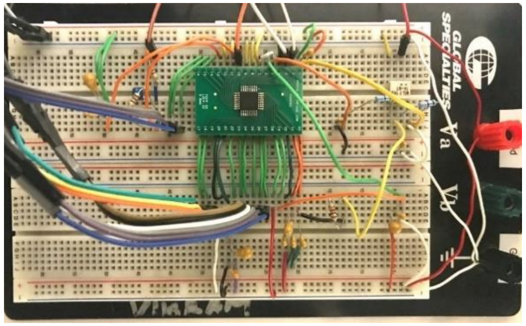
- Ongoing design to achieve a maximum of 80MHz sampling rate

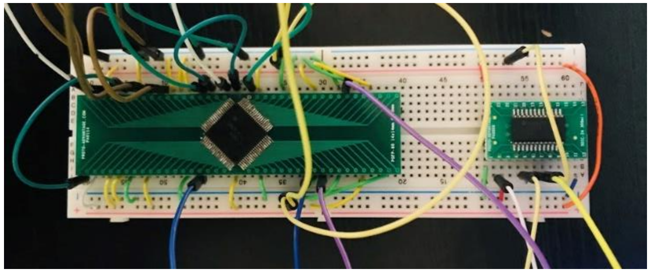
300-Volt Pulser board

***Martlet* mother board**









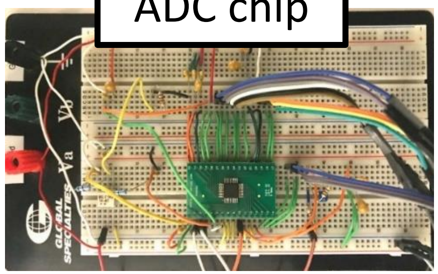
The evaluation breadboard for the three main components

ADC → Memory → P-S Converter → Martlet

- Components and connections are tested one by one for the entire communication
- An example 2.5 MHz sinewave is successfully sampled at 20 MHz rate and wirelessly collected

Sinewave 2.5MHz →

ADC chip



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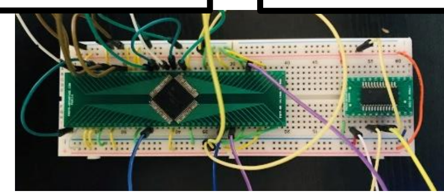
Memory | P-S Converter



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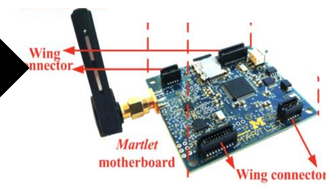
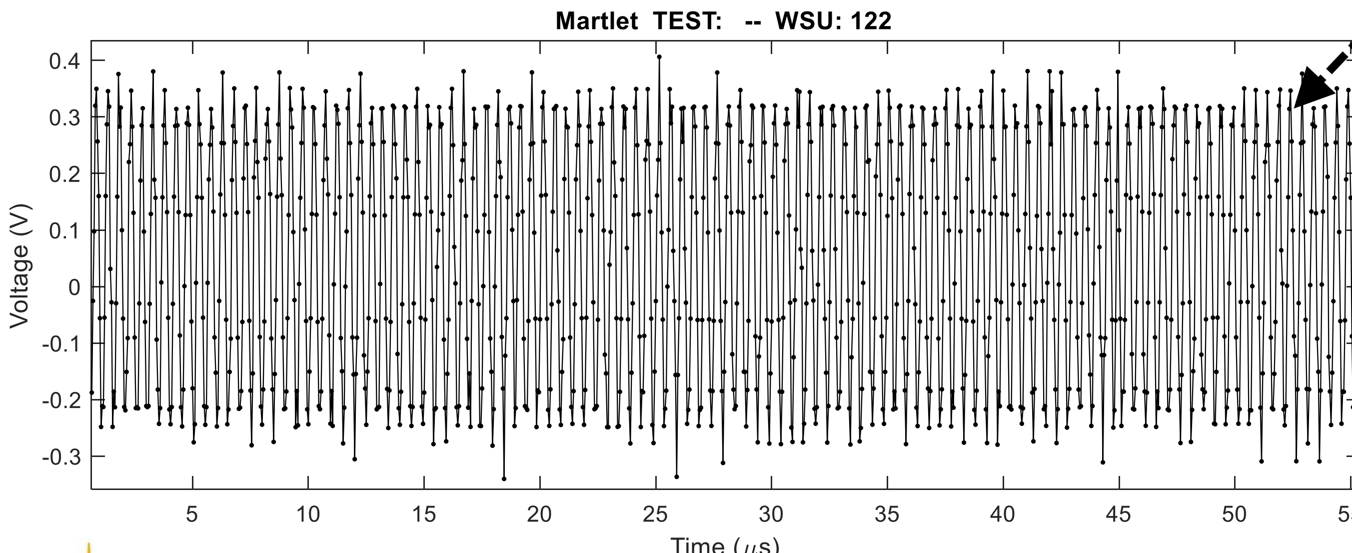
Martlet



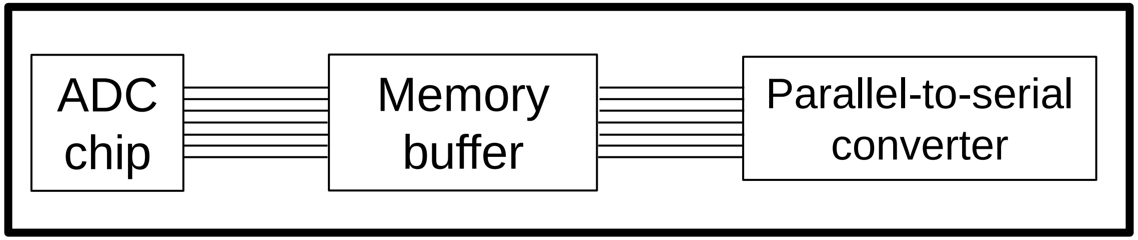
Wireless data collection

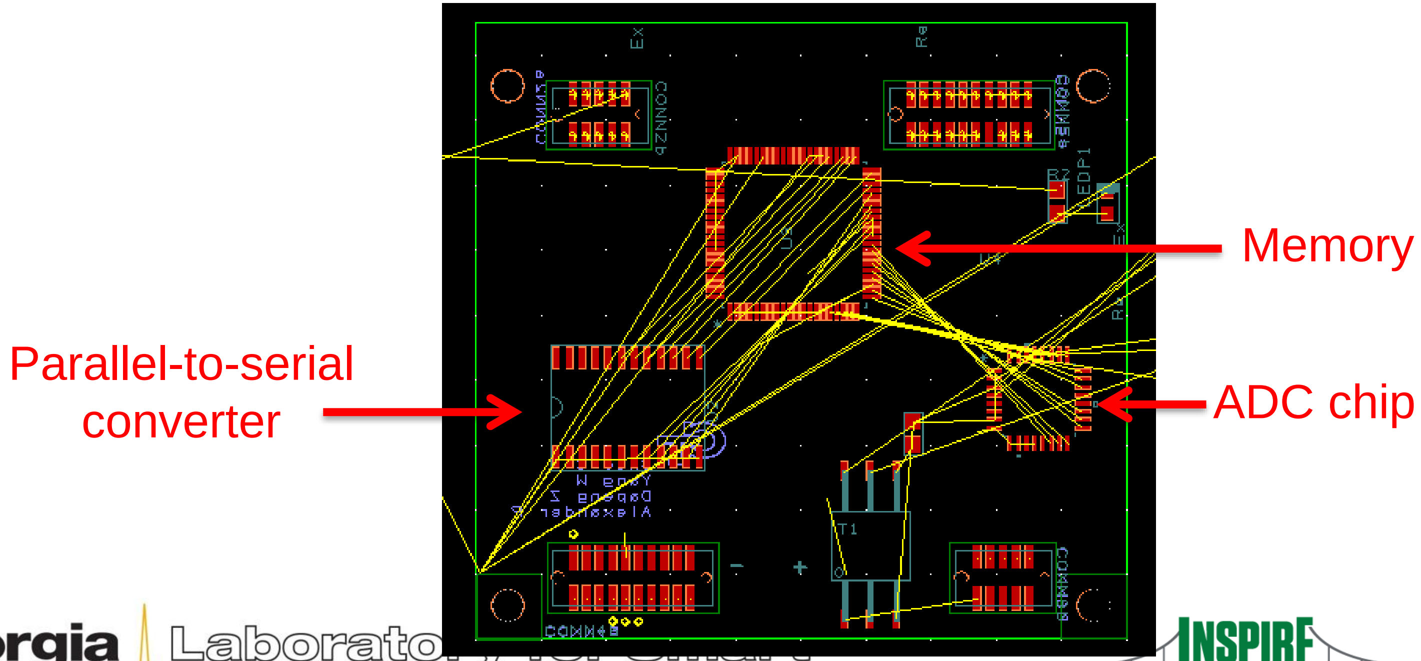


Ongoing Activities: PCB Design for the New Ultrasonic ADC Board

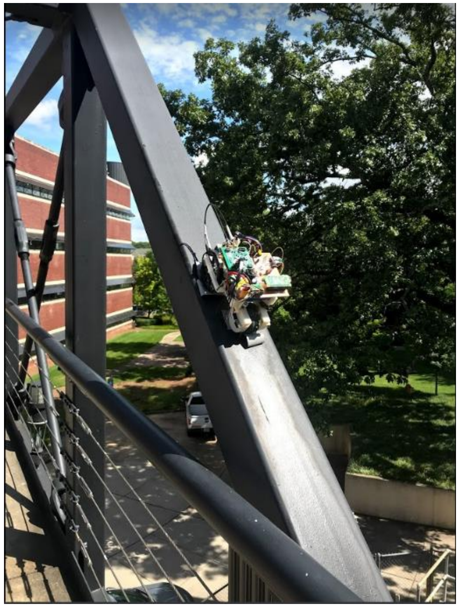
- After the breadboards show reliable and acceptable performance, printed circuit board (PCB) design will be finished for final evaluation.

Ultrasonic ADC board





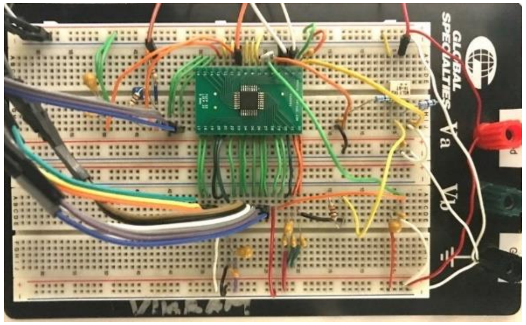
Conclusions

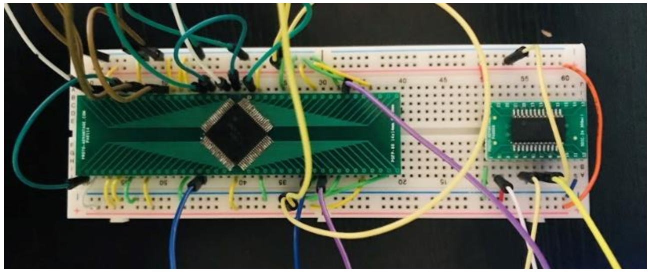


1. *Martlet* wireless ultrasonic device is integrated on a GT robot that mounts/retrieves a 1MHz transducer. However, the ultrasonic signal is not able to provide accurate thickness in the field test.

2. To improve the accuracy, the 300 Volt pulser board, 2.25MHz dual element transducer, and water couplant have been investigated. Laboratory testing shows that the method is effective even for thin and rusty steel members.

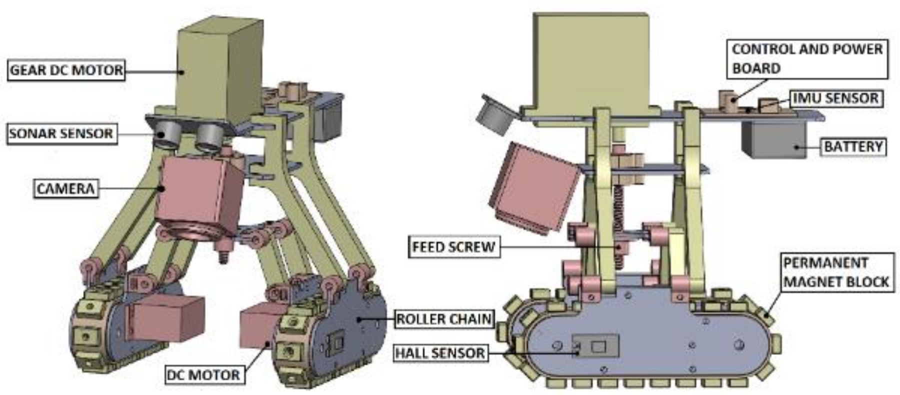
3. The new wireless ultrasonic board will achieve a maximum of 80MHz sampling rate, which greatly improves the resolution of the signal compared to the previous 3MHz sampling rate.

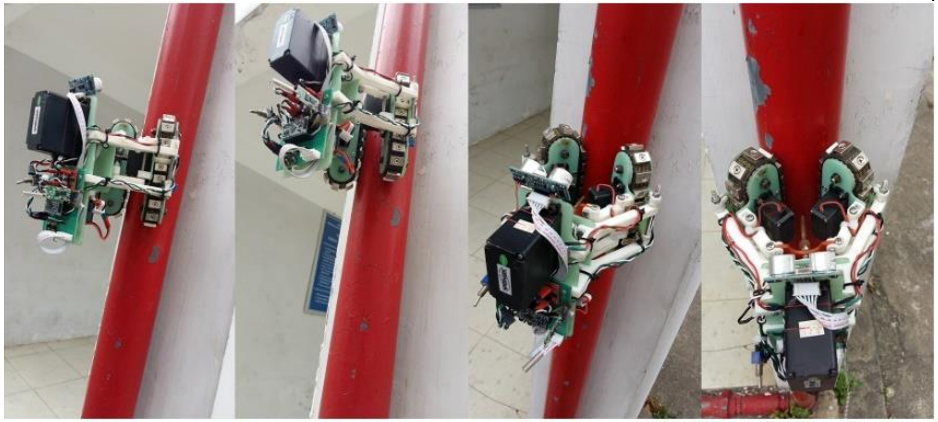




Future Work

- Upon PCB fabrication and validation, integration with the UNR robot will proceed.
- Mechanism to be added on the robot: (i) linear actuator for mounting/retrieving ultrasonic transducer; (ii) water couplant dispenser





Nguyen ST and La H (2019). "Development of a Steel Bridge Climbing Robot." Proc. of IEEE/RSJ International Conference on IROS, Macau, China, Nov. 3-8, 2019.

Acknowledgements

INSPIRE University Transportation Center
through USDOT/OST-R grant #69A3551747126

Thank You

Questions and Comments?