Robust Vibration Localization with Swarm-Intelligent Systems

Swarm Intelligence
Final Presentation
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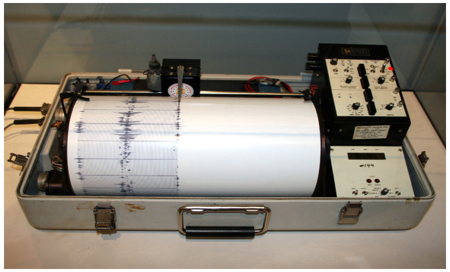
Talk Outline

- **Project Background**
  - **Seismography + Swarm-Intelligent Systems**
- Schematic Overview
- Multilateration
- Time Synchronization
- Data Acquisition / Processing
- Technical Limitations
- Results
- Future Research

Project Background (I)

[1]

- Seismography
  - Science of shock wave detection
  - Seismographs



[1]

Project Background (II)

- Unique Seismographic Approach: Swarm-Intelligent Systems
- Advantages
  - Inexpensive individual units
  - Distributed nature
    - Improved accuracy
    - Robustness
- Obstacles
  - Communication / synchronization
  - Weak Computation

Talk Outline

- Project Background
- **Schematic Overview**
  - **Experimental Setup**
  - **Project Outline**
- Multilateration
- Time Synchronization
- Data Acquisition / Processing
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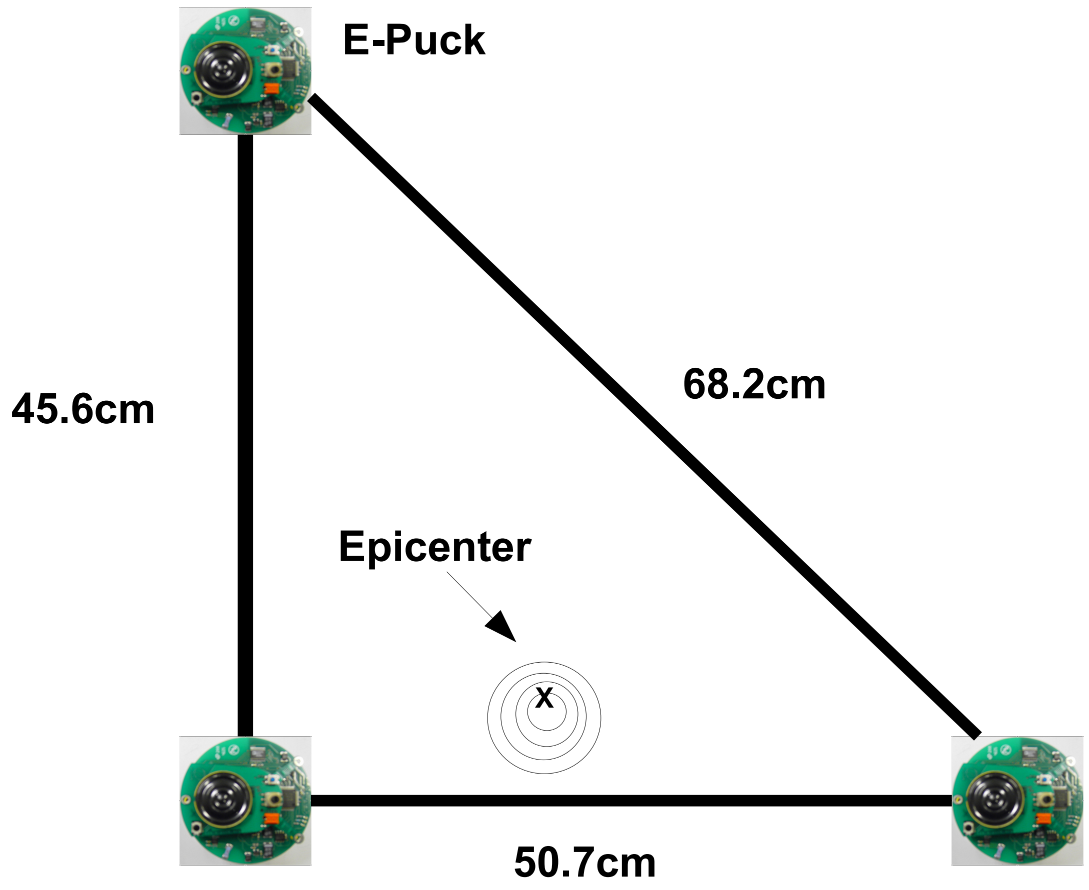
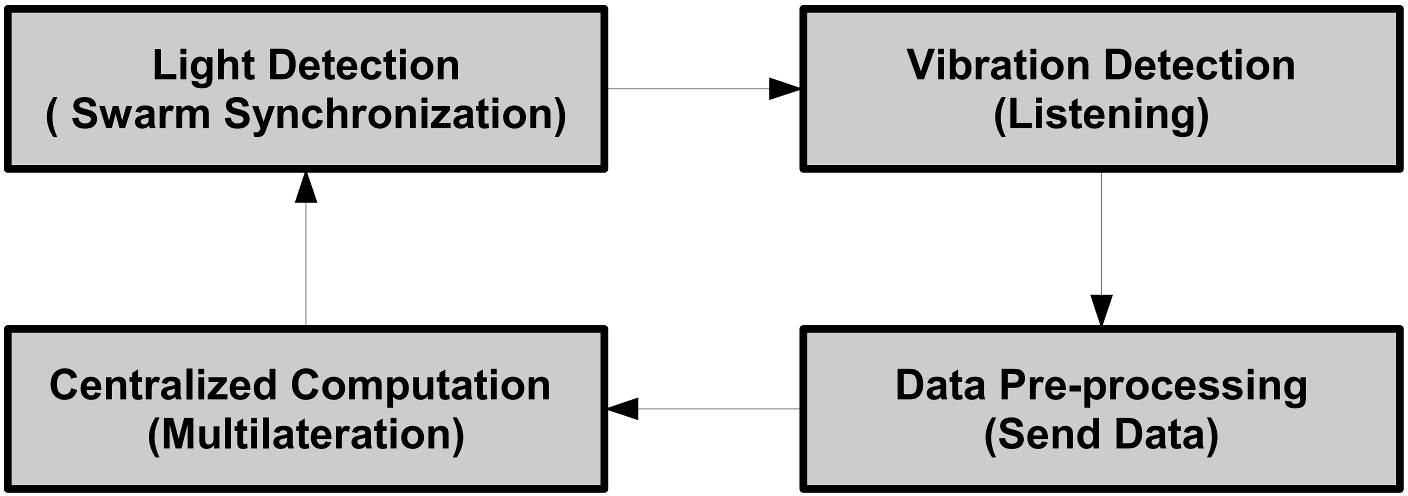
Experimental Setup



System Schematic



Talk Outline

- Project Background
- Schematic Overview
- **Multilateration**
  - **Formalisms**
  - **Simplifications**
  - **Finding solutions**
- Time Synchronization
- Data Acquisition / Processing
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Multilateration (I)

- Basic Principle:
  - Given various receivers and their geographic coordinates, isolate signal origin using time difference of arrival (TDOA).
- Formalism
  - Robots: R_i
  - Medium velocity: v_m
  - Time of arrival (TOA)

$$T_{R1} = \frac{1}{v_m}\sqrt{(x - x_{R1})^2 + (y - y_{R1})^2}$$

$$T_{R2} = \frac{1}{v_m}\sqrt{x^2 + y^2}$$

$$T_{R3} = \frac{1}{v_m}\sqrt{(x - x_{R3})^2 + (y - y_{R3})^2}$$

  - TDOA

$$T_{R12} = T_{R1} - T_{R2}$$

$$T_{R32} = T_{R3} - T_{R2}$$

Multilateration (II)

- Assumptions
  - Stationary robots
  - Predetermined geographic locations
  - Homogeneous medium (constant v_m)

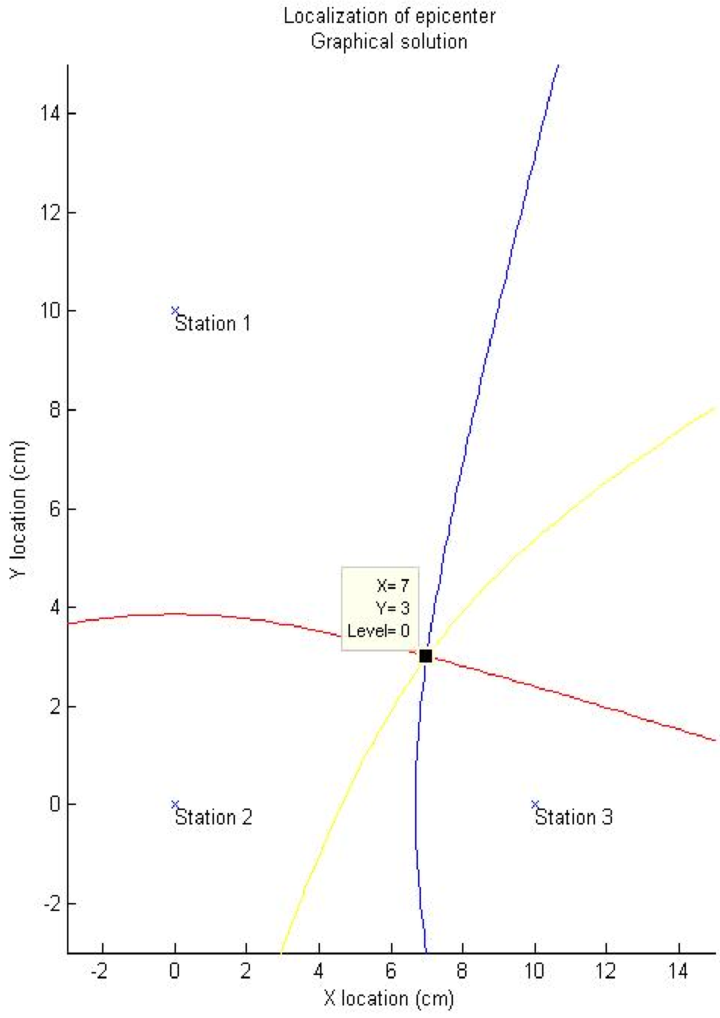
- Finding Solutions
  - Graphical
  - Bucher Method
  - Approximations

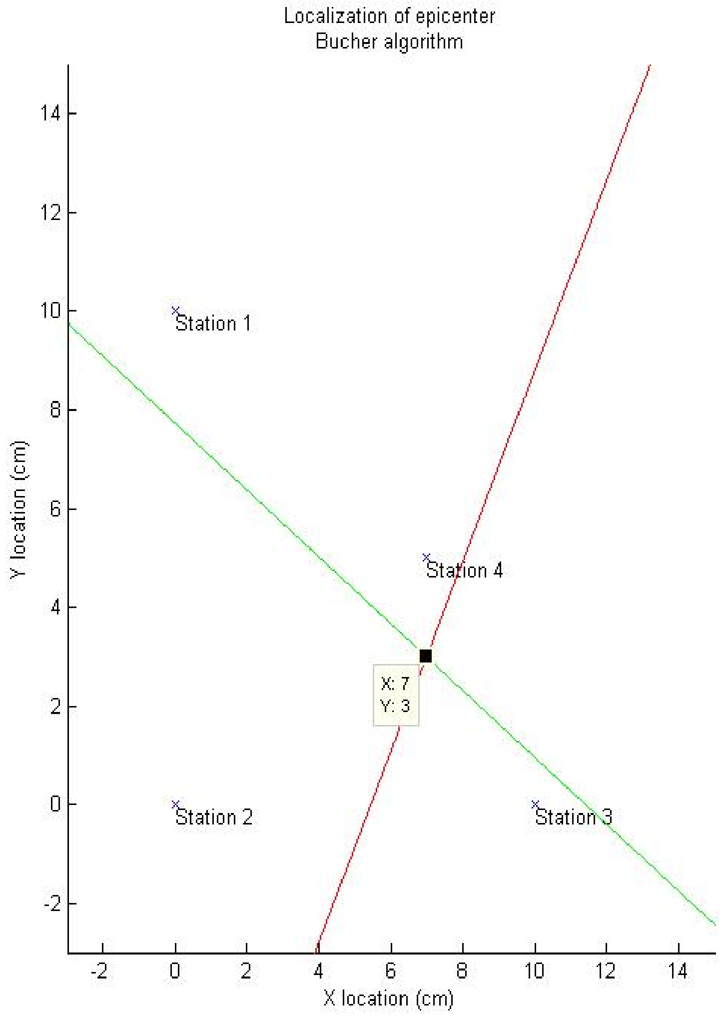
$$T_{R12} = T_{R1} - T_{R2} \qquad T_{R32} = T_{R3} - T_{R2}$$

$$T_{R12} = \frac{1}{v_m}\left[\sqrt{(x - x_{R1})^2 + (y - y_{R1})^2} - \sqrt{x^2 + y^2}\right]$$

$$T_{R32} = \frac{1}{v_m}\left[\sqrt{(x - x_{R3})^2 + (y - y_{R3})^2} - \sqrt{x^2 + y^2}\right]$$

Multilateration (III)





Talk Outline

- Project Background
- Schematic Overview
- Multilateration
- **Time Synchronization**
  - **Necessity and Method**
  - **Assumptions and Guarantee**
- Data Acquisition / Processing
- Technical Limitations
- Results
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Time Synchronization (I)

- Why synchronize?
  - Multilateration requires it!
- Method

  (1) Robots “listen” on IR port for significant change

  (2) Flash robots with an intense flash of light

  (3) Disable interrupts

  (4) Change listening mode to “vibration detection”

  (5) Start counter

  (6) Re-enable interrupts

  (7) Acquire “significant” values, disable interrupts

Time Synchronization (II)

- Implicit Assumption
  - Light reaches each E-Puck at the “same time”
  - 300 km/s for distances less than 0.5m

- Time Synchrony Guarantees
  - Via PIC register manipulation, we sample IR channel at same frequency on each E-Puck
  - Combination of same controller and disabling of interrupts guarantees same code execution

Talk Outline

- Project Background
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- **Data Acquisition / Processing**
  - **Pre-processing criteria**
  - **Communication to central unit**
  - **Centralized processing**
- Technical Limitations
- Results
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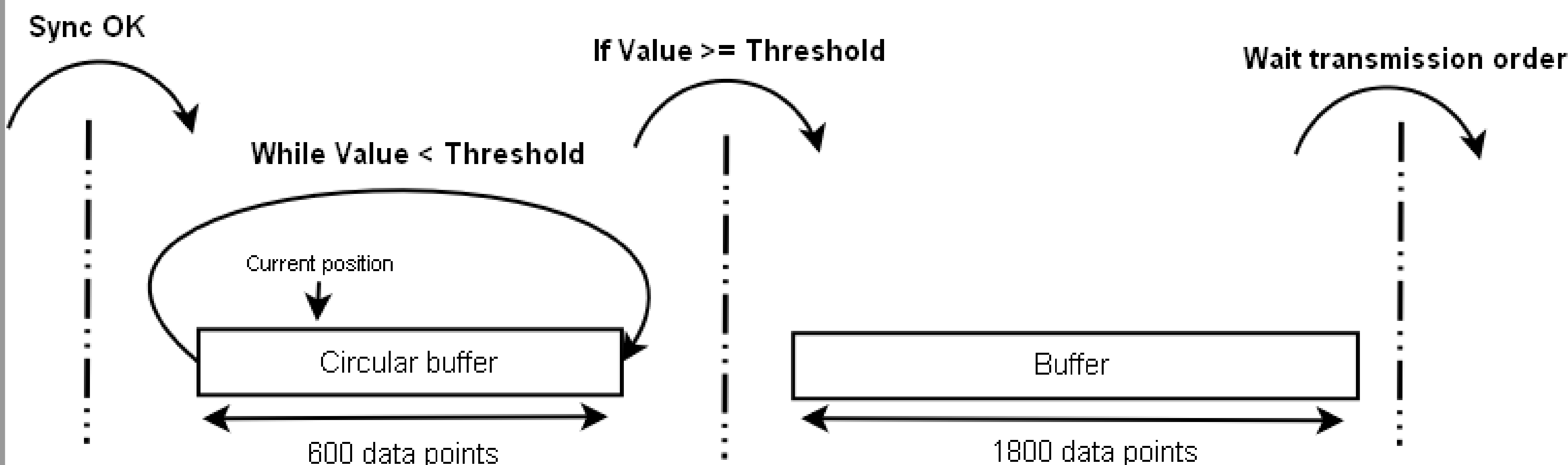
Data Acquisition (I)

- What constitutes data as being “significant”?
  - Empirically-defined threshold
    - Not robust
  - Adaptive thresholding
    - Computationally expensive (floating point arithmetic)
    - Time Synchronization fails
  - Empirically-defined threshold + signal signature
    - Simple and sure to capture all important wave characteristics

Data Acquisition (II)

- E-Puck on board process:

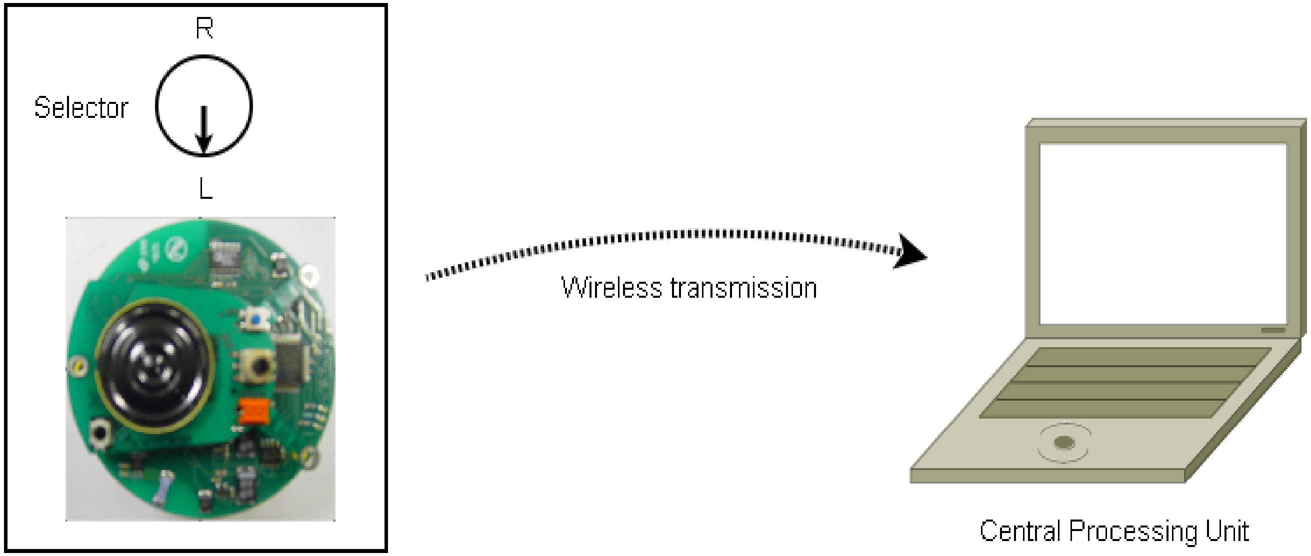


Pre-window buffer

Post-window buffer

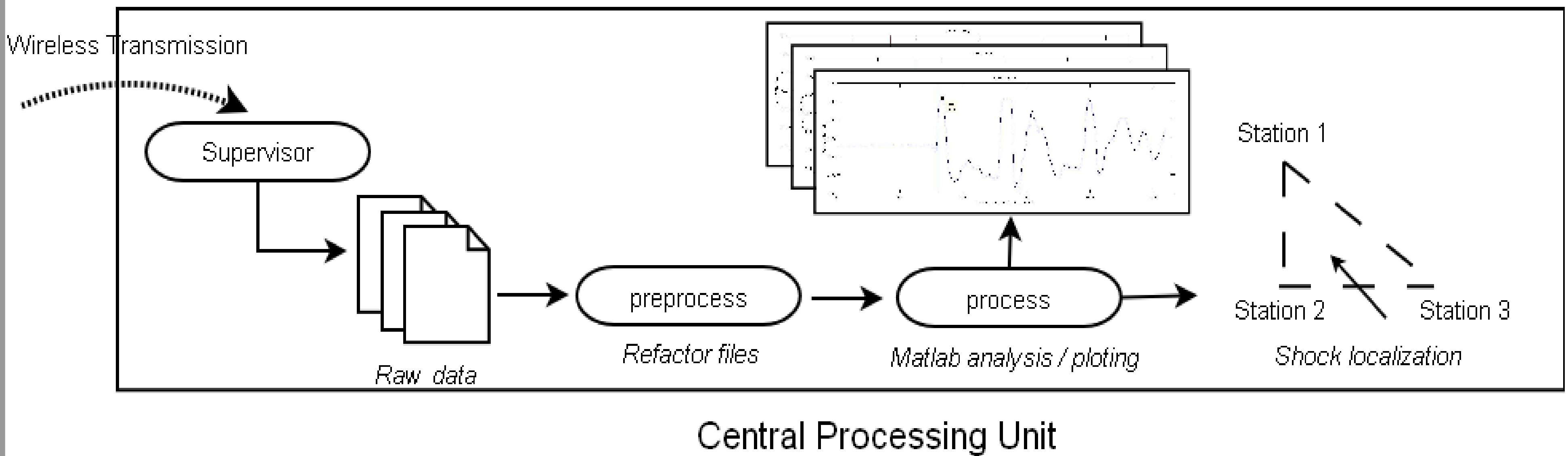
Data Acquisition (III)

- Communication transmission order:
  - Turn E-Puck selector to “left”
- Pre/Post window buffer transmitted to CPU



Data Processing

- Central processing schema



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- Data Acquisition / Processing
- **Technical Limitations**
  - **Accelerometer woes...**
- Results
- Future Research

Technical Limitations

- Micro controller
  - Emulated floating-point computation
- Autonomy
  - High power consumption
- **Accelerometer bandwidth response !!!**
  - $f_{-3db} = 150Hz$
  - Low-pass filter cuts out important frequency information
  - Timing information is inaccurate!

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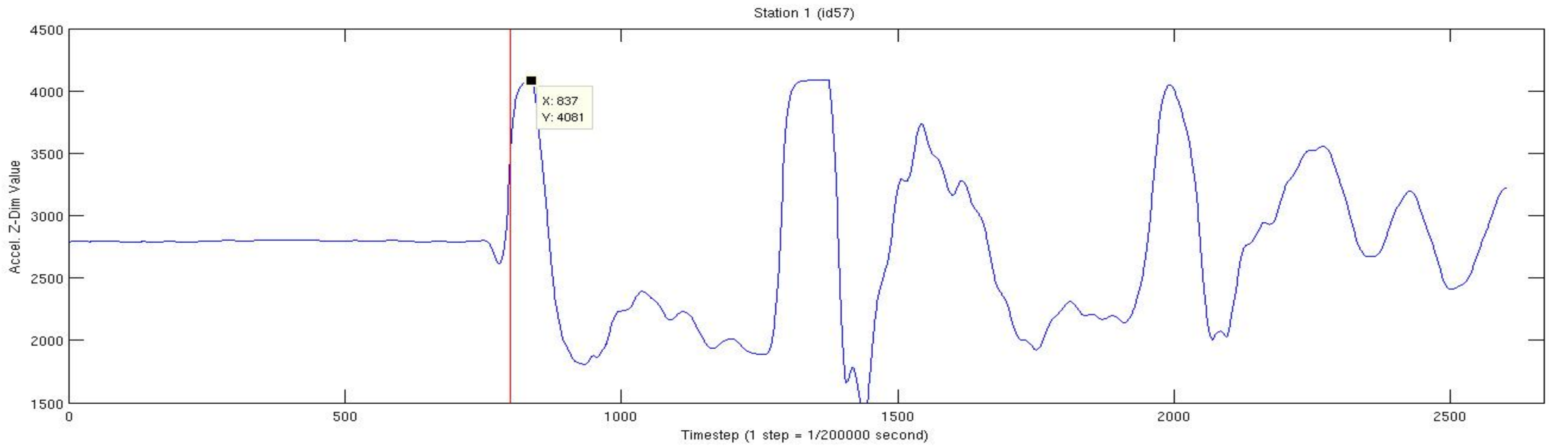
- Technical Limitations
- **Results**
  - **Medium velocity**
  - **Triangular setup**
- Future Research

Results: Medium Velocity (I)

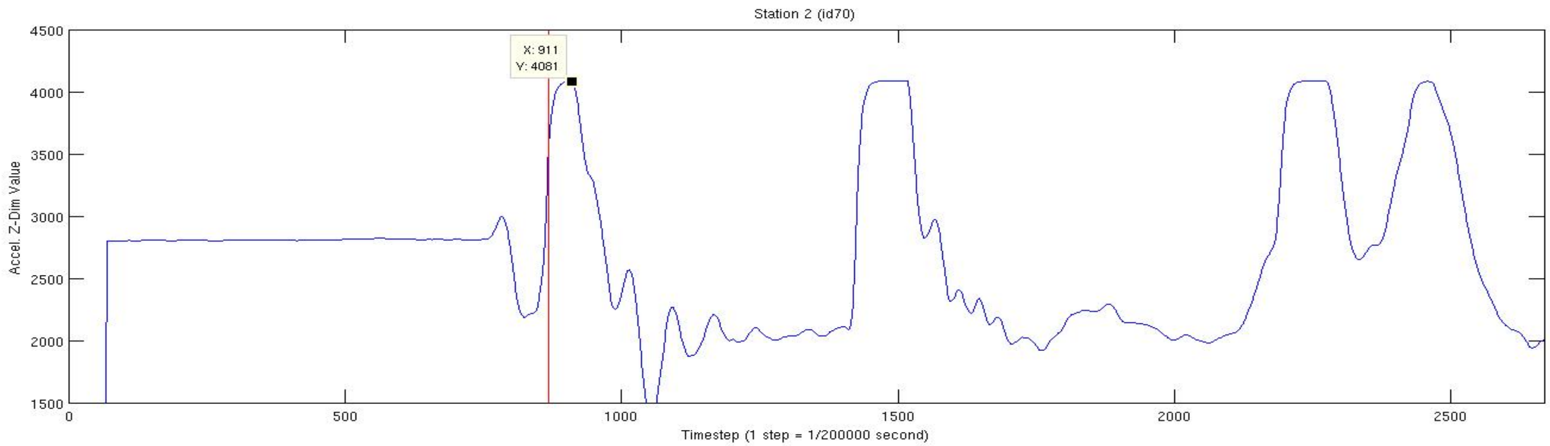
- Shock wave velocity measurement
  - Material: wood composite

- Experimental Setup

Results: Medium Velocity (II)



threshold(redline)=3500



Results: Medium Velocity (III)

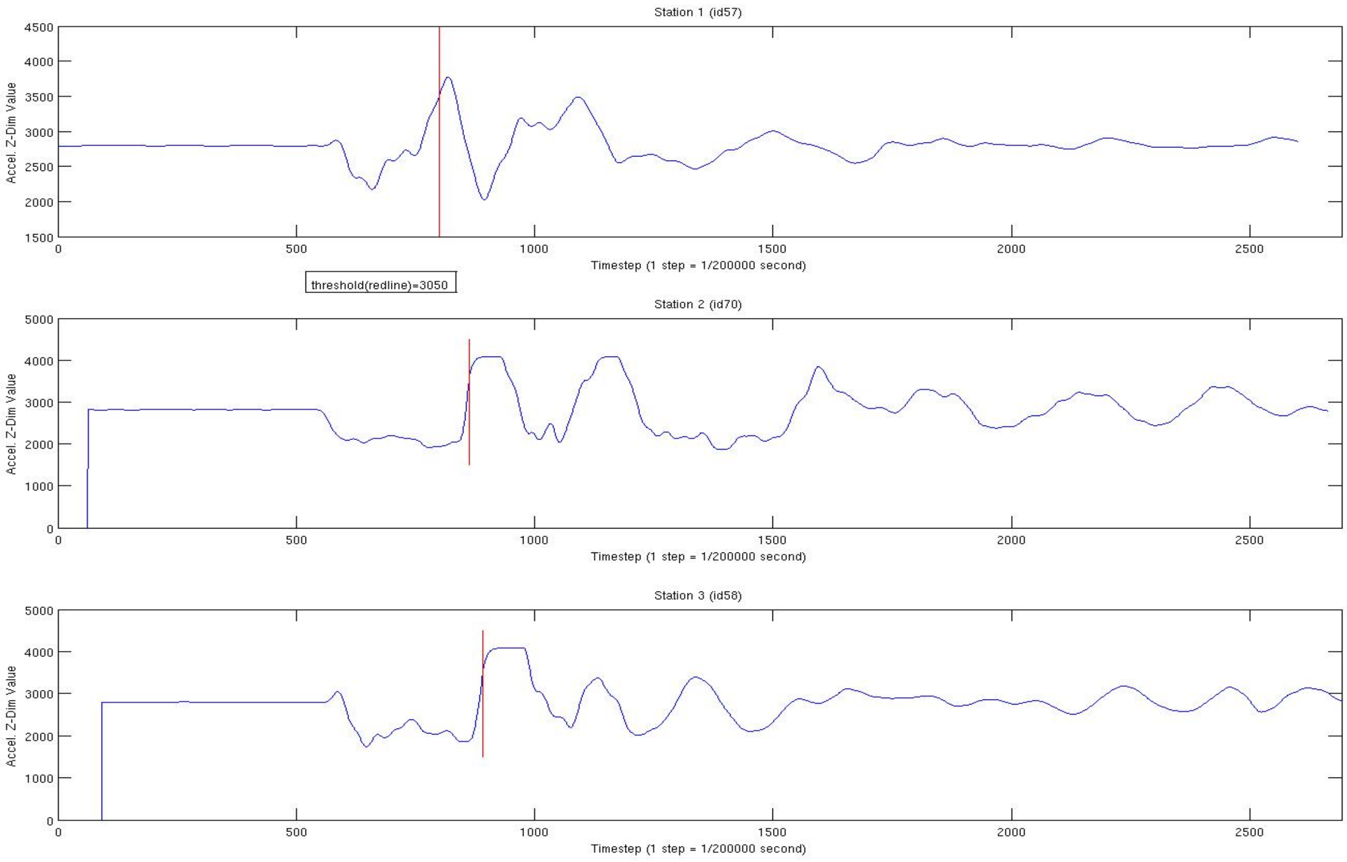
- Three experimental results

Experiment #	Measured Velocity
1	1697.1 m/s
2	802 m/s
3	752 m/s

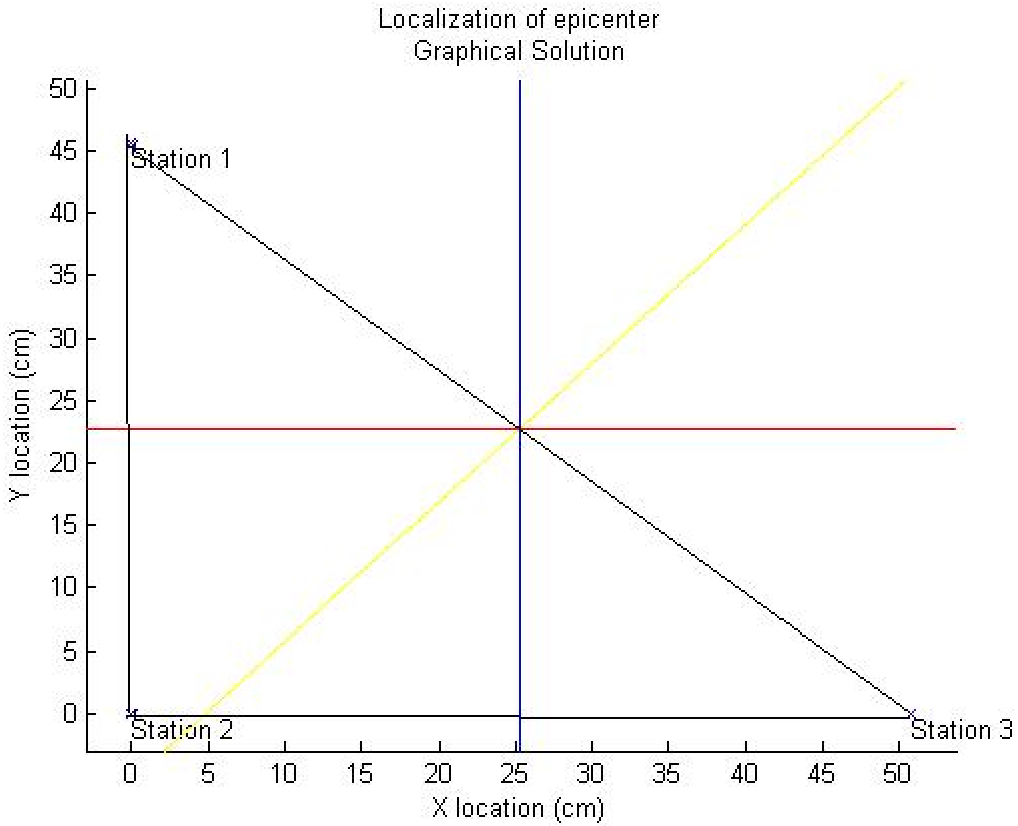
- Clearly timing information is skewed!
- Wave alignment done manually because of improper timing.

Results: Multilateration (I)

- Finding the epicenter



Results: Multilateration (II)



- Again, improper timing information (due to accelerometer readings) distorts multilateration results

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Future Research

- Hardware Changes
  - Appropriate signal capturing device
- Robot mobility
  - Honing in on “hot” epicenter zones
- Larger swarm size
  - Improved accuracy + analytical solution
  - Correlative models – heterogeneous environments

Questions

?

References + Credits

- References

[1] Seismography. http://en.wikipedia.org/wiki/Seismograph

[2] Multilateration. http://en.wikipedia.org/wiki/Multilateration

[3] Bucher, Ralph. *Exact Solution for Three Dimensional Hyperbolic Positioning Algorithm and Synthesizable VHDL Model for Hardware Implementation.* New Jersey Center for Wireless and Telecommunication. http://ralph.bucher.home.att.net/project.html

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[8] D T Pham. *Tangible Acoustic Interface Approaches.* Manufacturing Engineering Centre, Cardiff University, UK and Laboratoire Ondes et Acoustique, ESPCI, Paris, France.

- Photos

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