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Dual Use Ground Vehicle Condition-Based Maintenance Project B

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Project Objectives

- **Fatigue sensor for structural components** - *design, fabrication and testing*
- **Lubricant condition monitoring** - *sensor selection, experimentation and laboratory evaluation*
- **Wireless communication system** – *design and develop a sensor network*
- *Demonstration of a prototype system in a dual-purpose vehicle*



Project Team

Principal Investigators:

Dr. Muralidhar Ghantasala

- Sensors, fabrication, data acquisition and testing

Dr. Claudia Fajardo

- Engine lubricant condition monitoring

Dr. Ajay Gupta

- Wireless communication subsystem-design, interfacing, testing and evaluation

Dr. Daniel Kujawski

- Fatigue sensor-design, simulation, testing

Students:

Subash Gokanakonda – Fatigue sensor

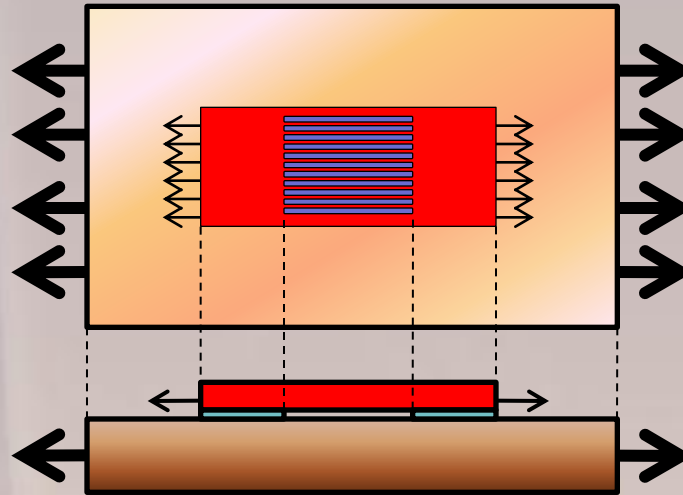
Ryan J. Clark – Lubricant condition monitoring

Andrew Hovingh & Madhuri Revalla - wireless networking

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How a fatigue sensor works?



- Detects and monitors the fatigue damage at a critical location
- Strains in ligaments resemble the actual strain field at a critical location
- Ligaments fail due to fatigue in a sequence from the ligament experiencing the highest to the lowest strains

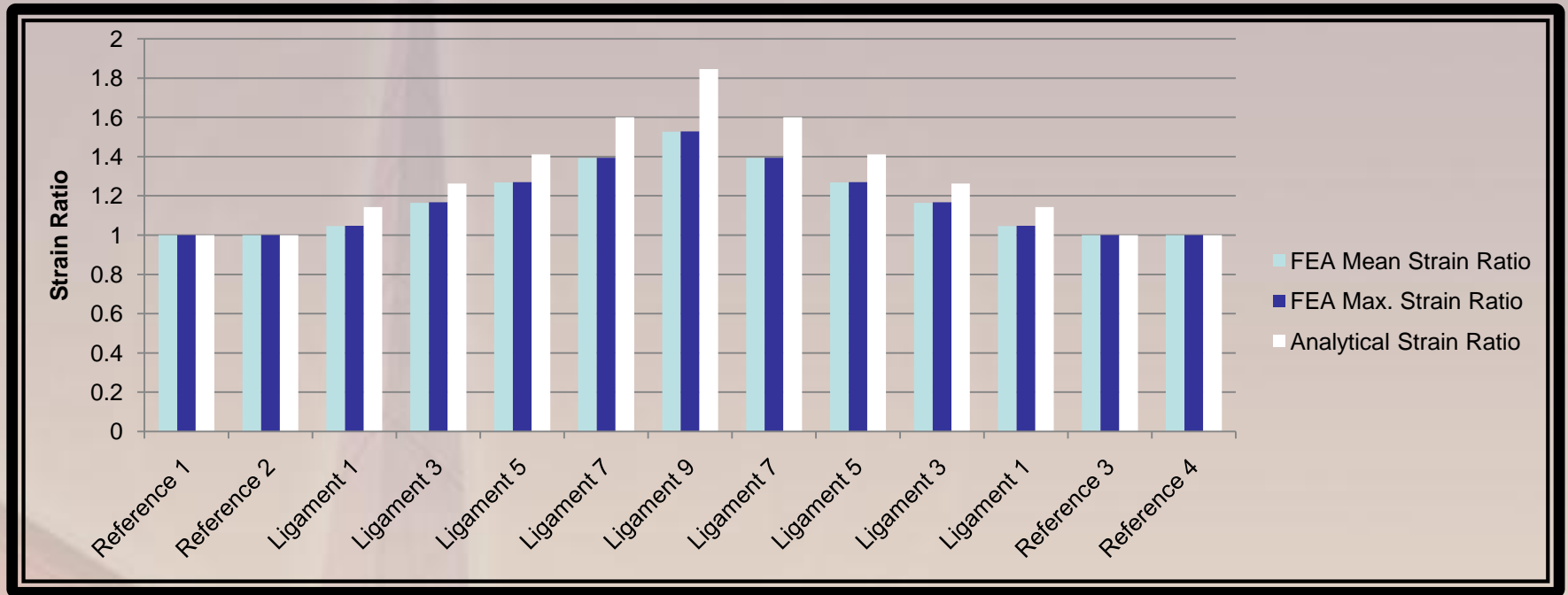
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Important Characteristics

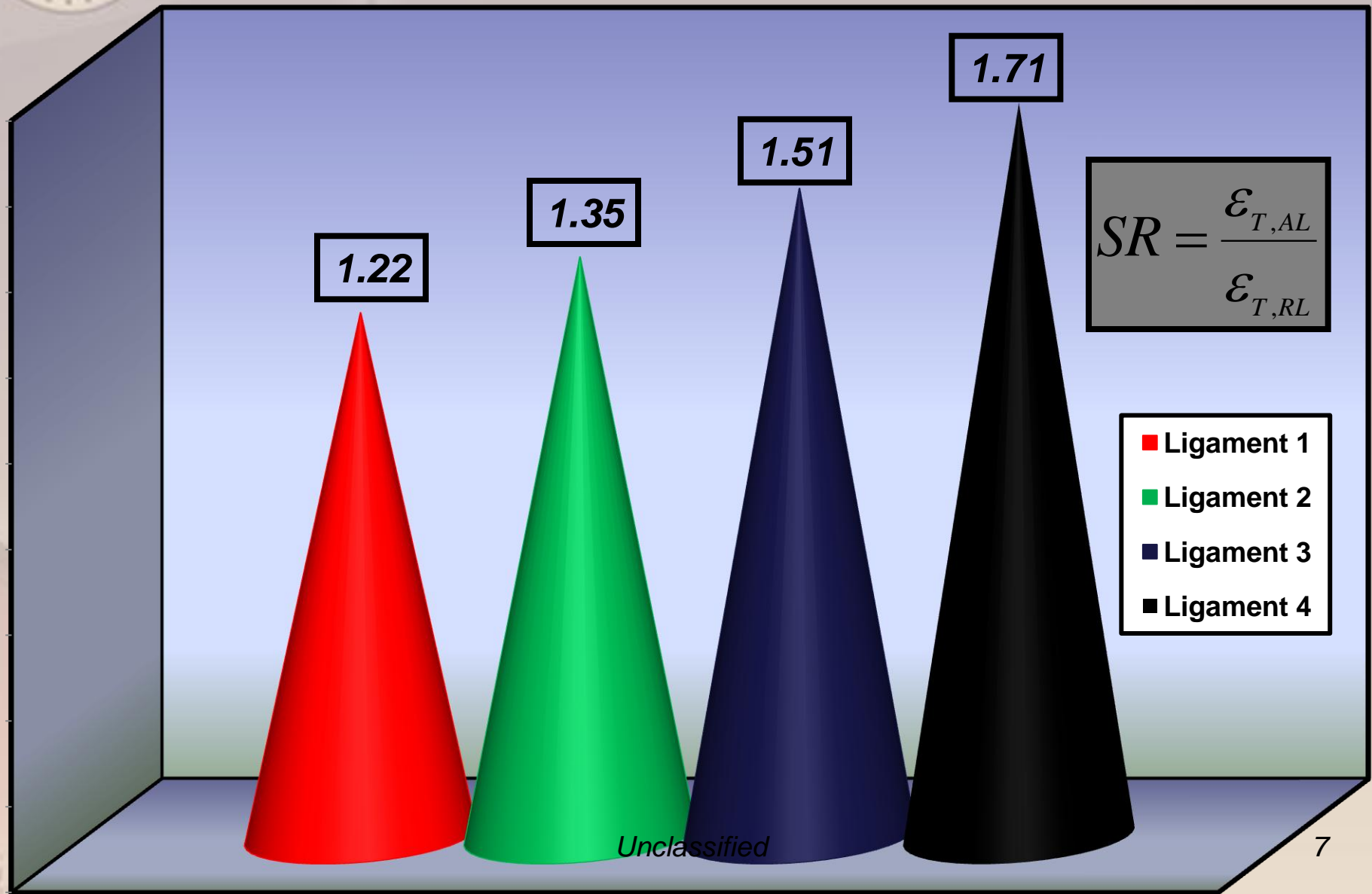
- Placed at a suitable distance from a critical location
- Made from the same material or different material than that of the structure
- Used on new structures or on those already in service
- Experiences same cyclic strains and environmental conditions as the critical location
- Enables real-time on-board fatigue life monitoring
- Supports **C**ondition **B**ased **M**aintenance (CBM)

Strain Magnification: Comparison



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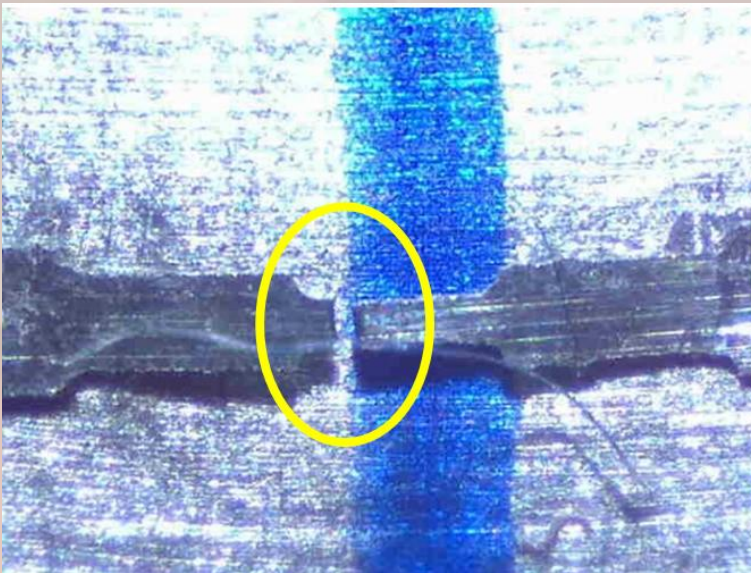
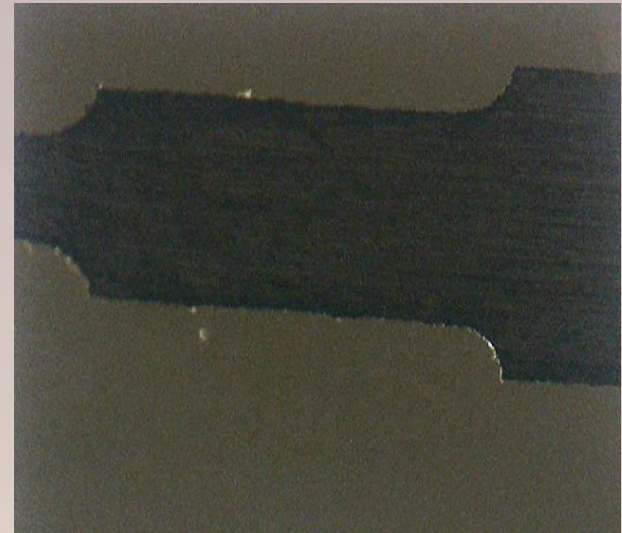
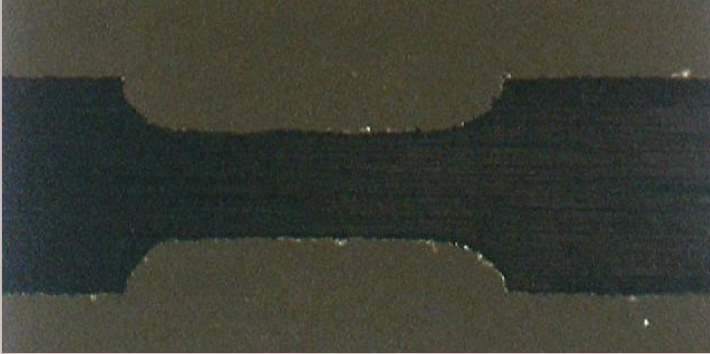
Strain Ratio



Fatigue sensor (active part) in Stainless Steel

$$L_g = 1 \text{ mm}$$

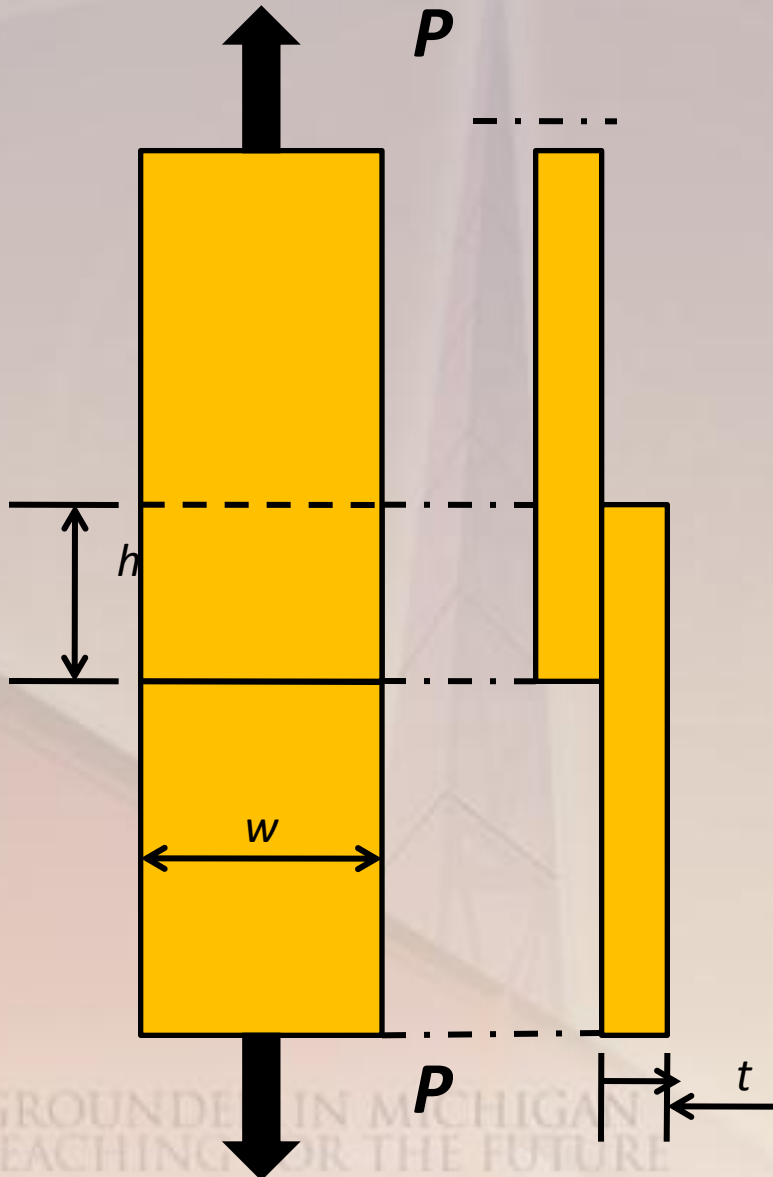
$$H = 4.5 \text{ mm}$$



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Glue-Adhesive Testing



Shear strength,

$$\tau_{Test} = \frac{P}{(h * w)}$$

Normal stress,

$$\sigma_{test,normal} = \frac{P}{(w * t)}$$

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Work Plan

- FEA simulations are being conducted using an elastic-plastic material model
- The properties of the adhesives for gluing the fatigue sensor on to test structures are under investigation
- Different manufacturing techniques are being evaluated. The first set of sensors will be manufactured using milling and laser machining



Lubricant Condition Monitoring Strategies

- Goal
 - Quantify the degree and rate of oil degradation in a JP-8 fueled diesel engine through direct, on-board monitoring of lubricant properties
- Objectives
 - Establish correlations between contamination levels and changes in lubricant properties
 - Validate the relationship between published threshold limits on contaminant level and lubricant properties
 - Determine the effect of engine operating conditions on lubricant properties

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Equipment

- **Engine**
 - Naturally-aspirated, 6.5 Liter (detuned) V-8 diesel
 - Coupled engine-dynamometer setup and instrumentation
- **Lubricant-condition monitoring sensor**
 - Temperature ($-40\text{ }^{\circ}\text{C} < T < +150\text{ }^{\circ}\text{C}$)
 - Dynamic viscosity ($0 < \mu < 50\text{ cP}$)
 - Dielectric constant ($1 < \kappa < 6$)
 - Density ($0 < \rho < 1.5\text{ g/cm}^3$)
- **Mounting location**
 - Ensure sufficient fluid contact with sensor



Engine

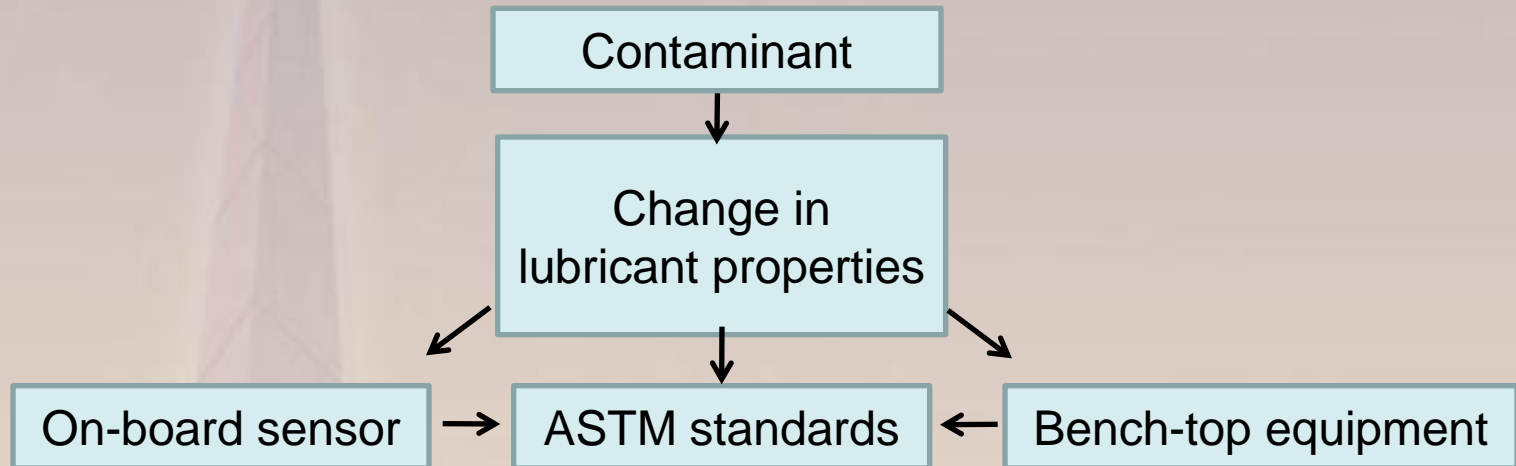


Lubricant sensor



Benchmarking Experiments

- Bench-top
 - Assess contaminant effects (e.g. fuel, water, soot) on lubricant properties
 - Validate sensor output against ASTM standards



- Engine
 - Monitor lubricant properties directly with the oil-condition sensor
 - Validate sensor output and identify contaminants



Results: Validation of Prototype Sensor Output

Baseline measurements

Property	Sensor	Validation	Mfr. Spec.	Difference% (validation vs. MS)	Discrepancy (sensor vs. validation)
Viscosity at 40 °C (cSt)	96.2 +/- 0.9	123.2 +/- 0.1	118	4%	21.9%
Viscosity at 100 °C (cSt)	14.1 +/- 0.7	15.2 +/- 0.7	15.7	3%	7%
Dielectric const. at 40 °C	2.22 +/- 0.01	2.38 +/- 0.01	n/a	n/a	6.7%
Flash Point (°F)	n/a	419 +/- 5	415	1%	n/a

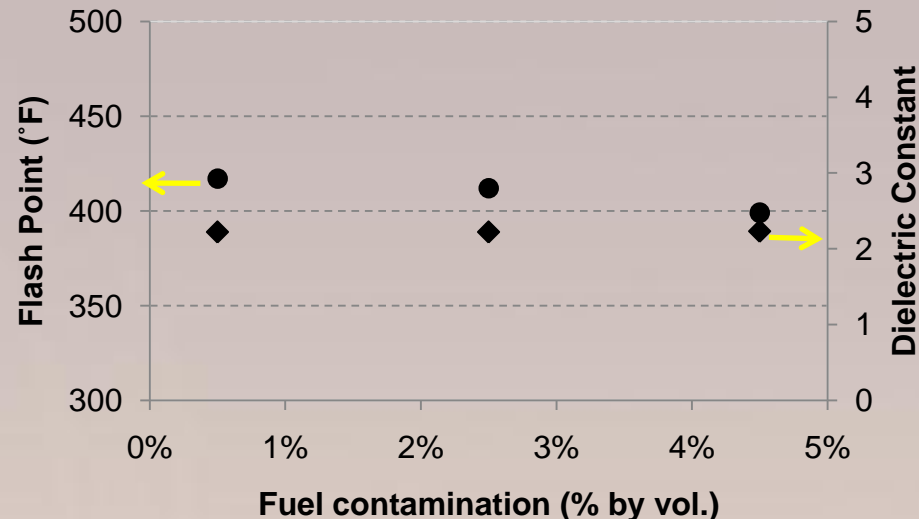
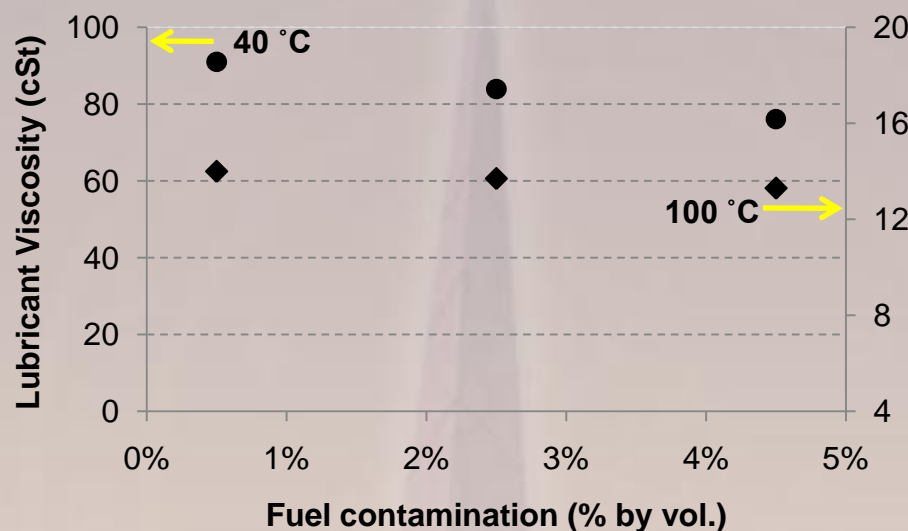
Lubricant contamination (2.5% fuel by vol.)

Property	Sensor Output	Validation Measurement	Discrepancy (sensor vs. validation)
Viscosity at 40 °C (cSt)	89.1 +/- 0.7	117 +/- 0.4	23.7% *
Viscosity at 100 °C (cSt)	13.7 +/- 0.1	14.3 +/- 0.1	5%
Dielectric const. at 40 °C	2.22 +/- 0.02	2.39 +/- 0.01	7%
Flash Point (°F)	n/a	412 +/- 1	n/a

- Very good precision established
- Discrepancy between sensor output and bench-top measurements $\leq 7\%$ for viscosity at 100 °C and dielectric constant
- Investigating discrepancies for viscosity measurement at 40 °C



Results (continued)



- Decrease in viscosity with increasing temperature
- Decrease in viscosity with fuel contamination
- Decrease in flash point with fuel contamination
- No change in dielectric constant for 2.5% vol. fuel contamination



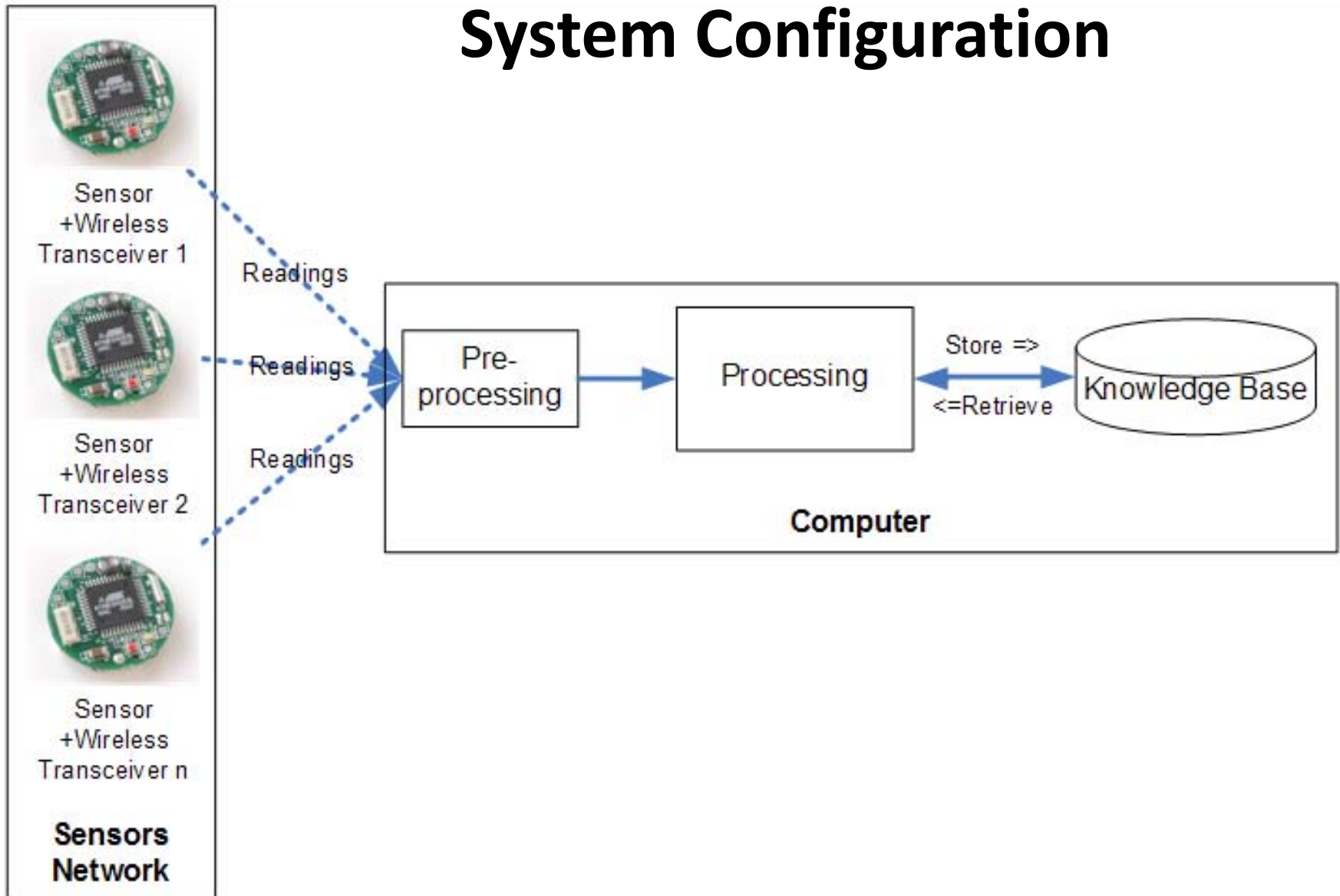
Wireless Communication Strategy

Objectives

- Design a wireless, self-sufficient, low-power, scalable and cost-effective sensor-data communication system using off-the-shelf devices (microcontrollers, radio transceivers, amps, A/D converters...) for ground vehicles
- Build a prototype of wireless network system that stores and displays sensor data from the engine and structural components



System Configuration

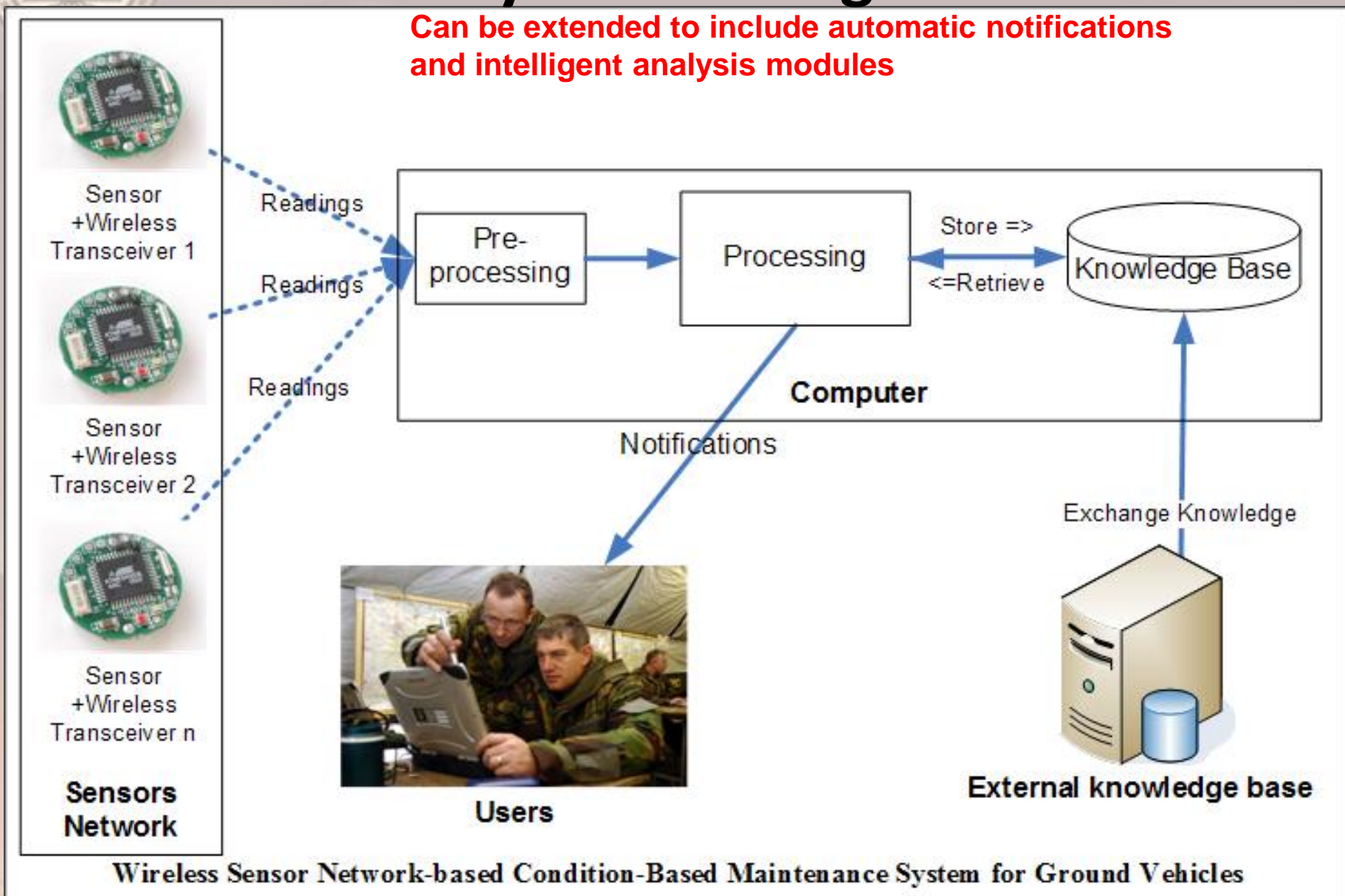


Wireless Sensor Network-based Condition-Based Maintenance System for Ground Vehicles



System Configuration

Can be extended to include automatic notifications and intelligent analysis modules





Evaluated Device Configurations

- Texas Instrument's MSP430 micro-controller + Chipcon transceiver
 - Inexpensive, configurable
 - Low level programming (more software development time)
- Crossbow's MICA motes
 - Integrated controller + radio, costlier
 - NesC programming (less development time)
- Characteristics
 - Low power, low duty-cycle (on/off)
 - 900MHz and 2.4GHz bands
 - Communication standards: 802.15.4 and ISM band compliant and ZigBee ready



Challenges

- Harsh environments (e.g. high temperature)
 - MSP430, CC chips, and Crossbow motes can tolerate up to 185°F
- Connectivity
 - Interference (with other communication equipments, and other transceivers)
 - Signal degradation (Faraday cage effect from the vehicle, temperature-resistant enclosures)
- Fault-tolerance
 - Provide built-in redundancy in the communication network



Summary

- 1. Fatigue sensor design** – First stage of the design and numerical simulation has been completed. Manufacturing strategies are being explored.
- 2. Lubricant monitoring sensor has been identified.** Literature review has been completed. A dual-purpose diesel engine has been procured and is being set-up with the required instrumentation.
- 3. Wireless communication strategies are being evaluated.** Texas Instrument's MSP430 microcontroller- based and Crossbow's motes- based systems are shortlisted for further evaluation. Simple system configurations are being tested in the laboratory.



Thank you

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