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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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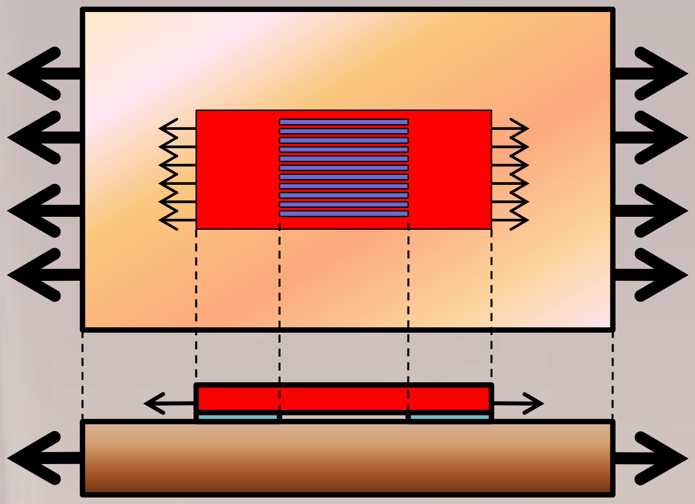
How a fatigue sensor works?

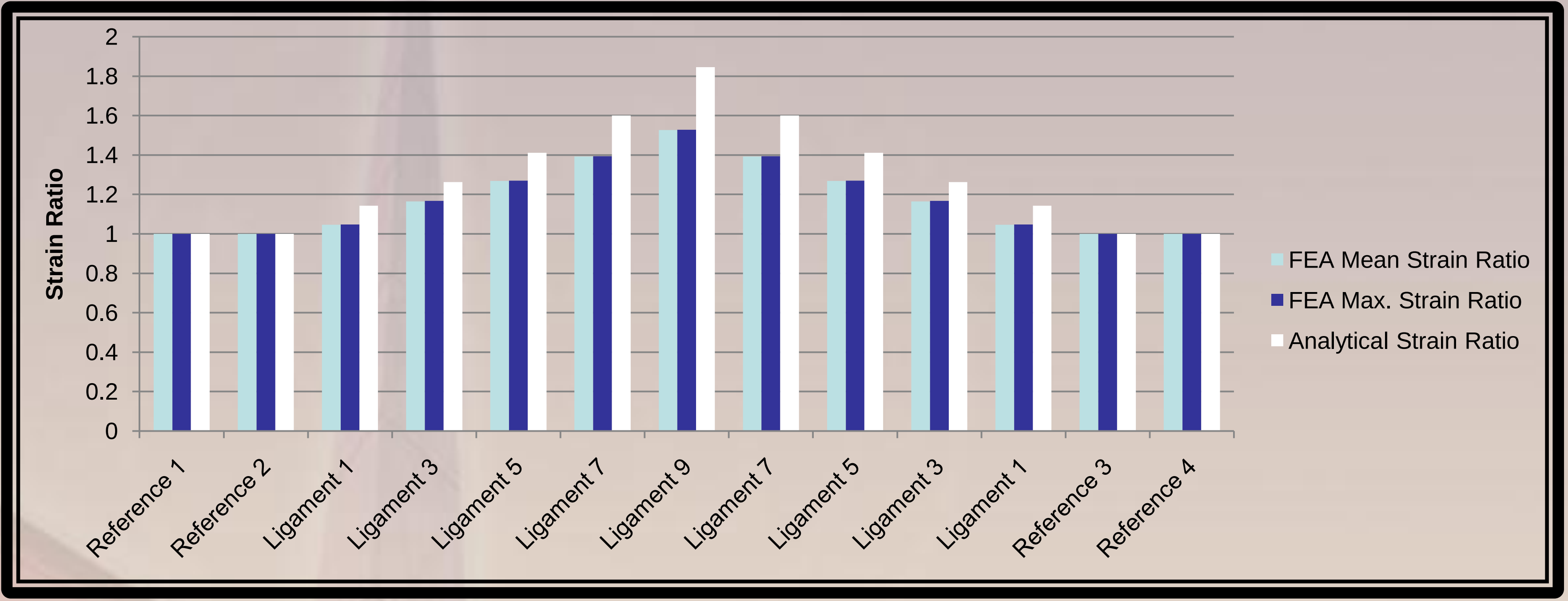


- Detects and monitors the fatigue damage at a critical location
- Strains in ligaments resemble the actual strain field at a critical location
- Ligaments fail due to fatigue in a sequence from the ligament experiencing the highest to the lowest strains

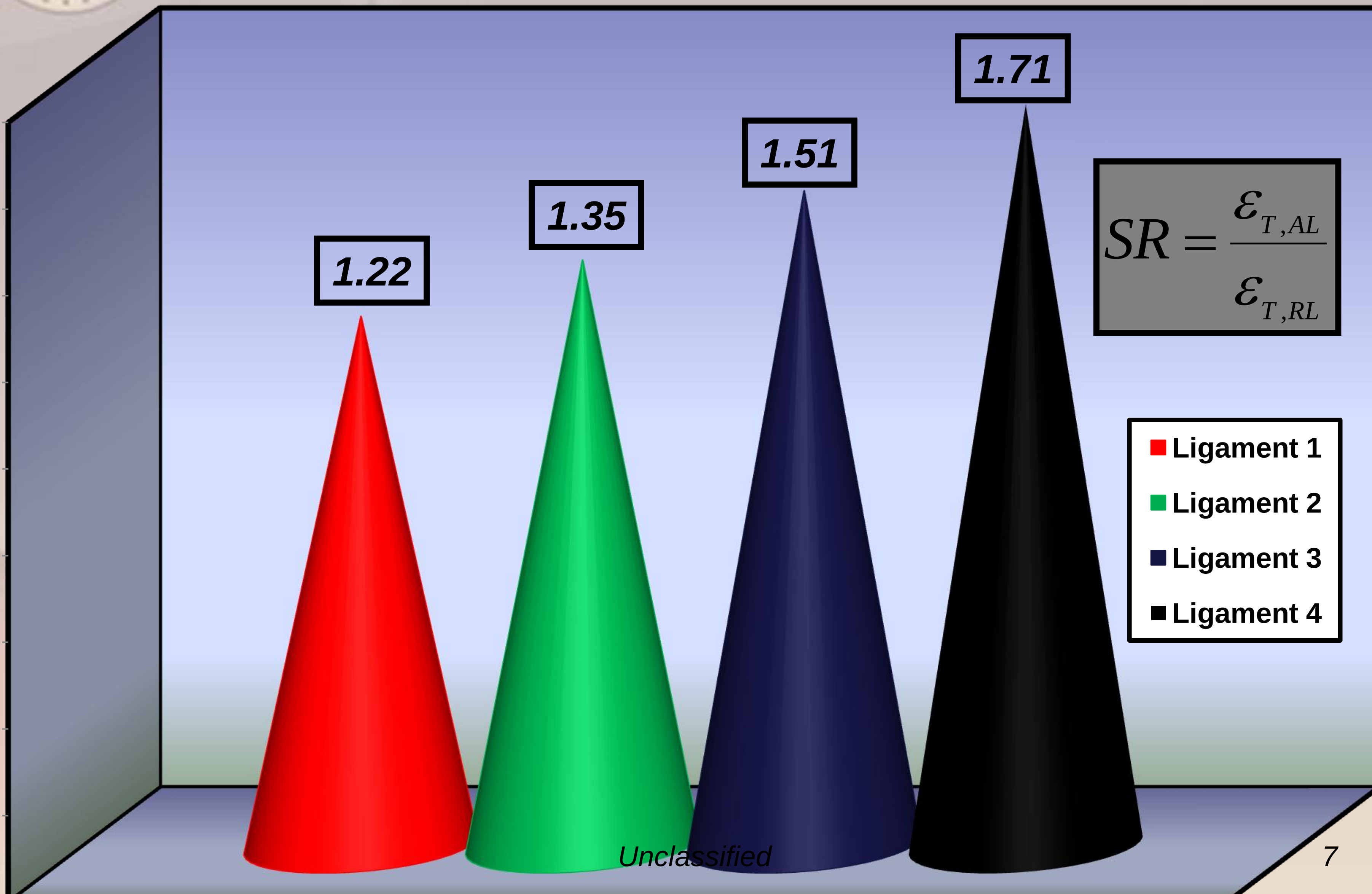
Important Characteristics

- 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

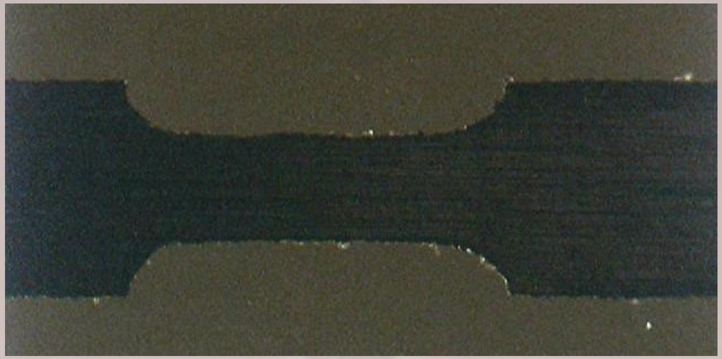


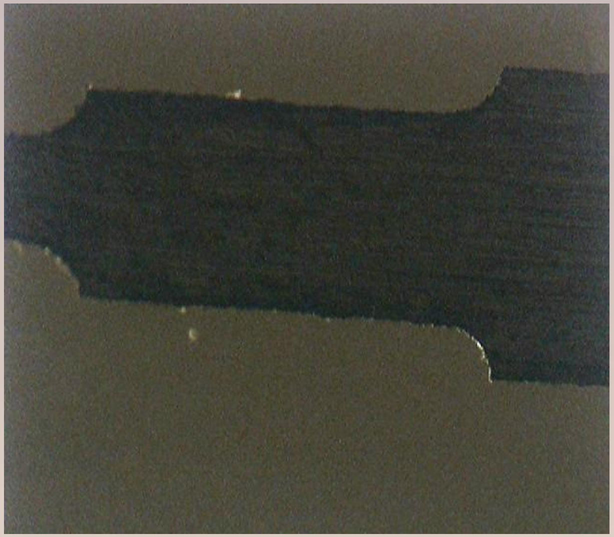
Strain Ratio

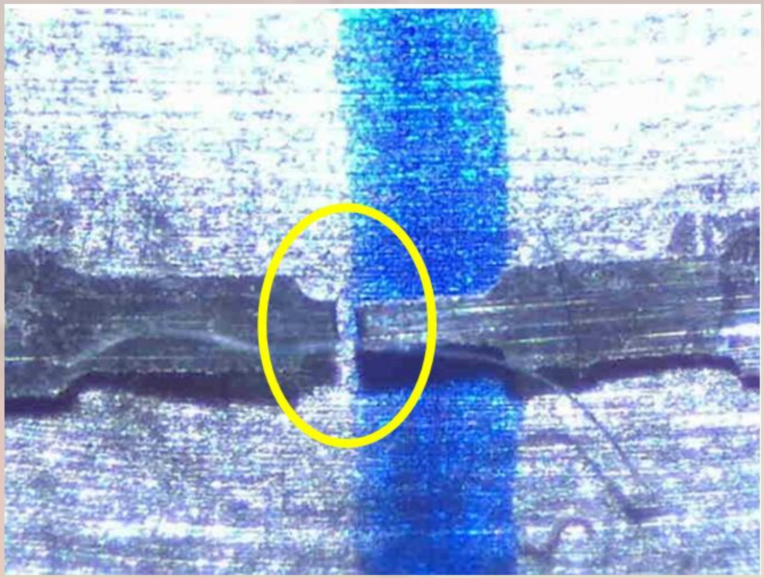


Fatigue sensor (active part) in Stainless Steel

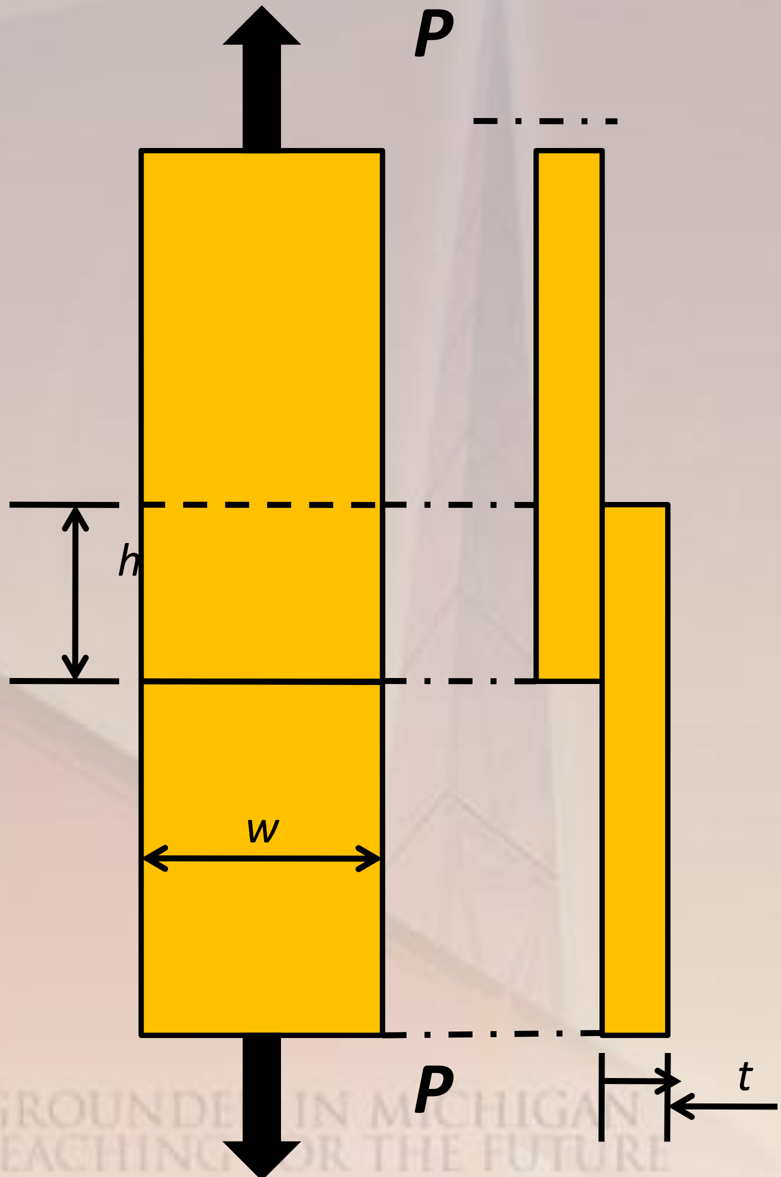
L_g = 1 mm ***H = 4.5 mm***







Glue-Adhesive Testing



Shear strength,

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

Normal stress,

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

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

Equipment

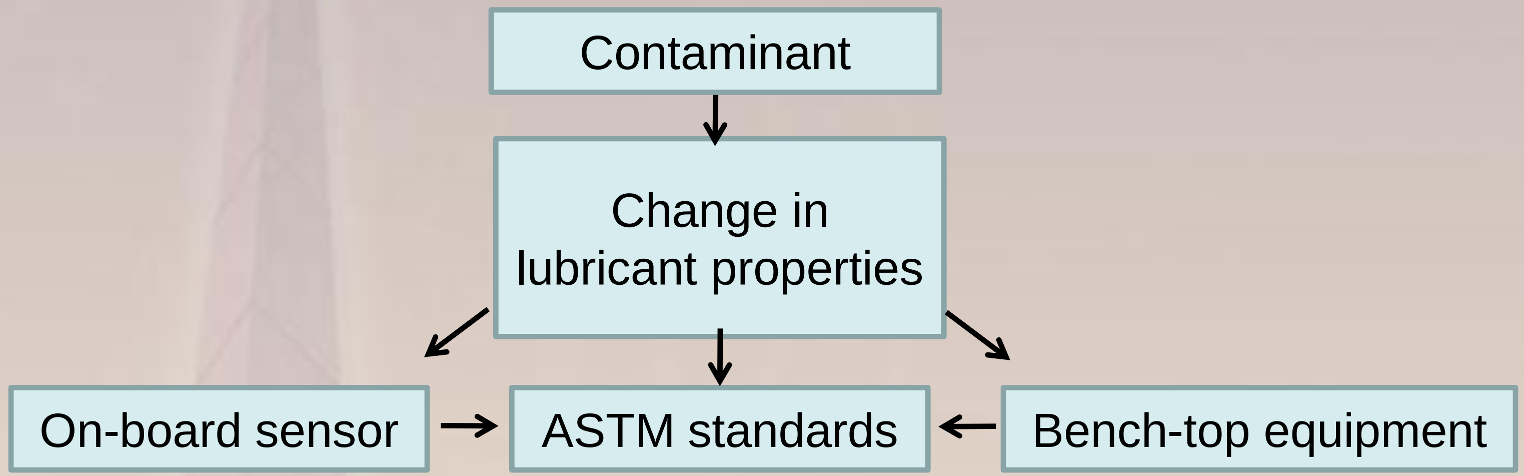
- **Engine**
  - Naturally-aspirated, 6.5 Liter (detuned) V-8 diesel
  - Coupled engine-dynamometer setup and instrumentation
- **Lubricant-condition monitoring sensor**
  - Temperature (-40 °C < T < +150 °C)
  - Dynamic viscosity (0 < μ < 50 cP)
  - Dielectric constant (1 < κ < 6)
  - Density (0 < ρ < 1.5 g/cm³)
- **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

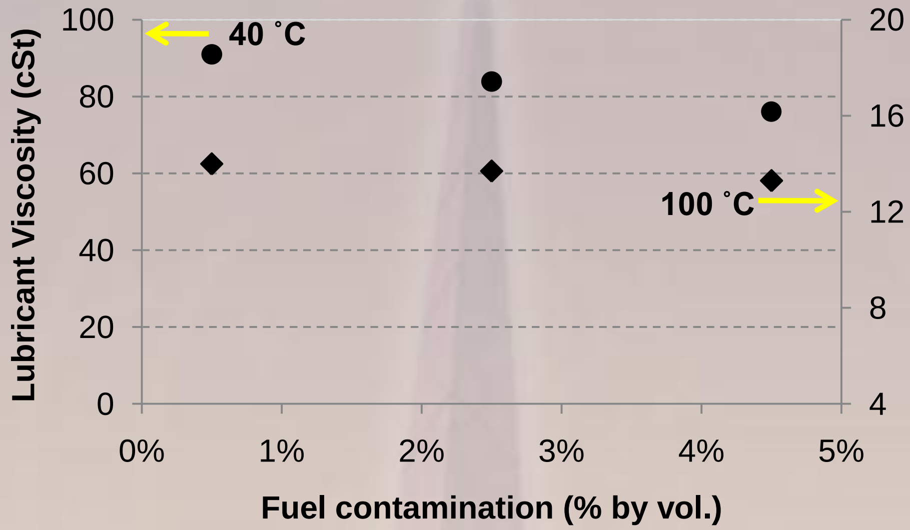
Property	Sensor	Validation	Mfr. Spec.	Difference% (validation vs. MS)	Discrepancy (sensor vs. validation)
Viscosity at 40 ˚C (cSt)	96.2 +/- 0.9	123.2 +/- 0.1	118	4%	21.9%
Viscosity at 100 ˚C (cSt)	14.1 +/- 0.7	15.2 +/- 0.7	15.7	3%	7%
Dielectric const. at 40 ˚C	2.22 +/- 0.01	2.38 +/- 0.01	n/a	n/a	6.7%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

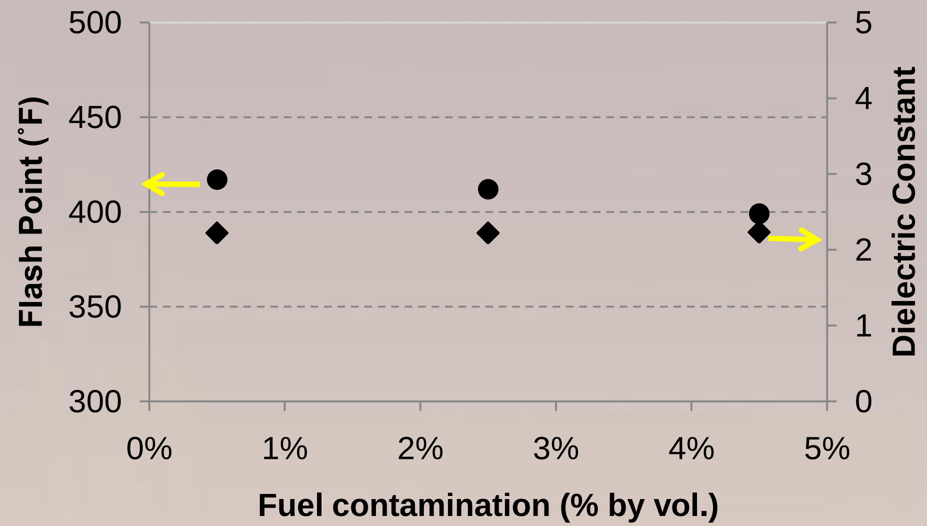
Lubricant contamination (2.5% fuel by vol.)

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 ≤ 7% for viscosity at 100 °C and dielectric constant
- Investigating discrepancies for viscosity measurement at 40 °C

Results (continued)





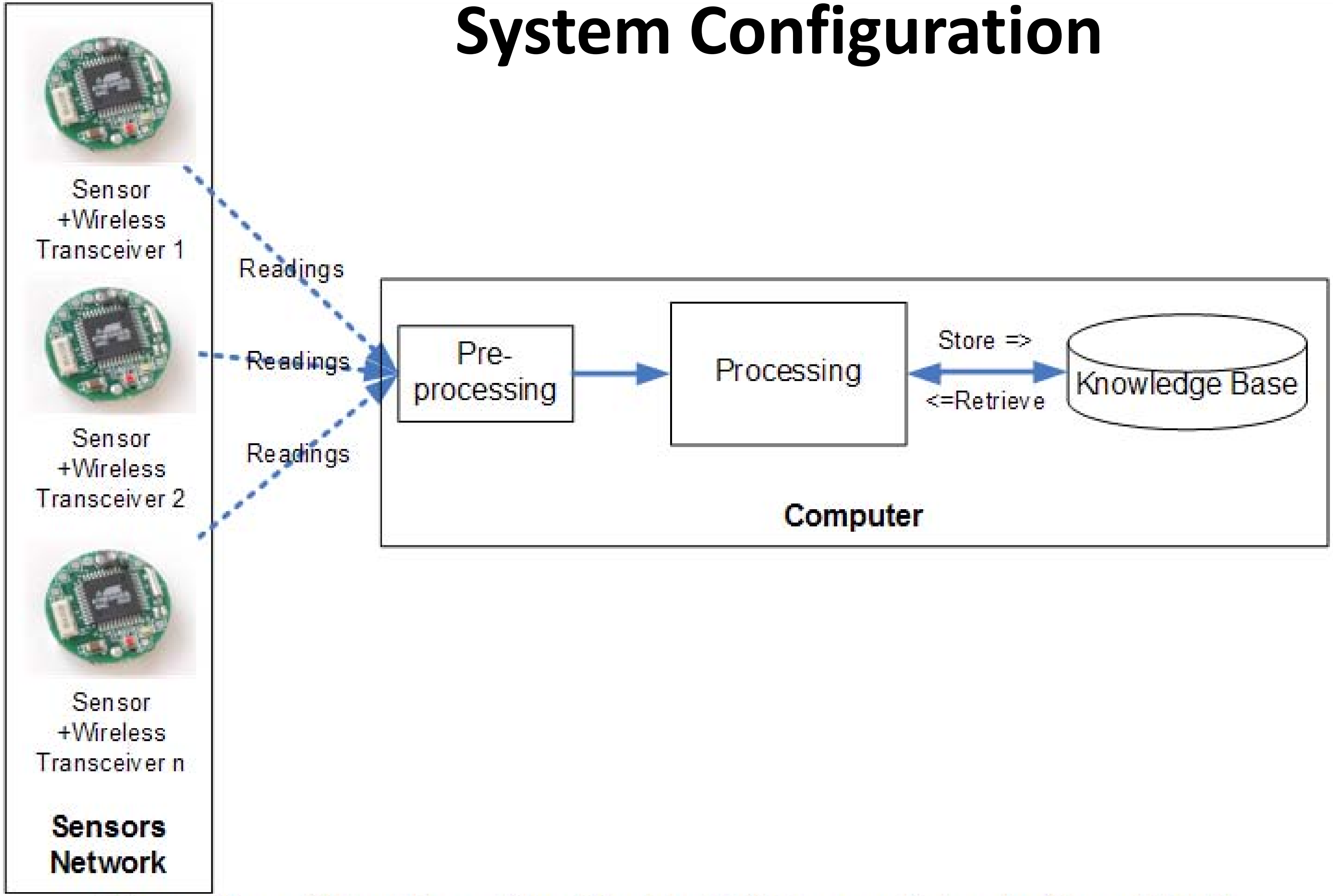
- Decrease in viscosity with increasing temperature
- Decrease in viscosity with fuel contamination
- Decrease in flash point with fuel contamination
- No change in dielectric constant for 2.5% vol. fuel contamination

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

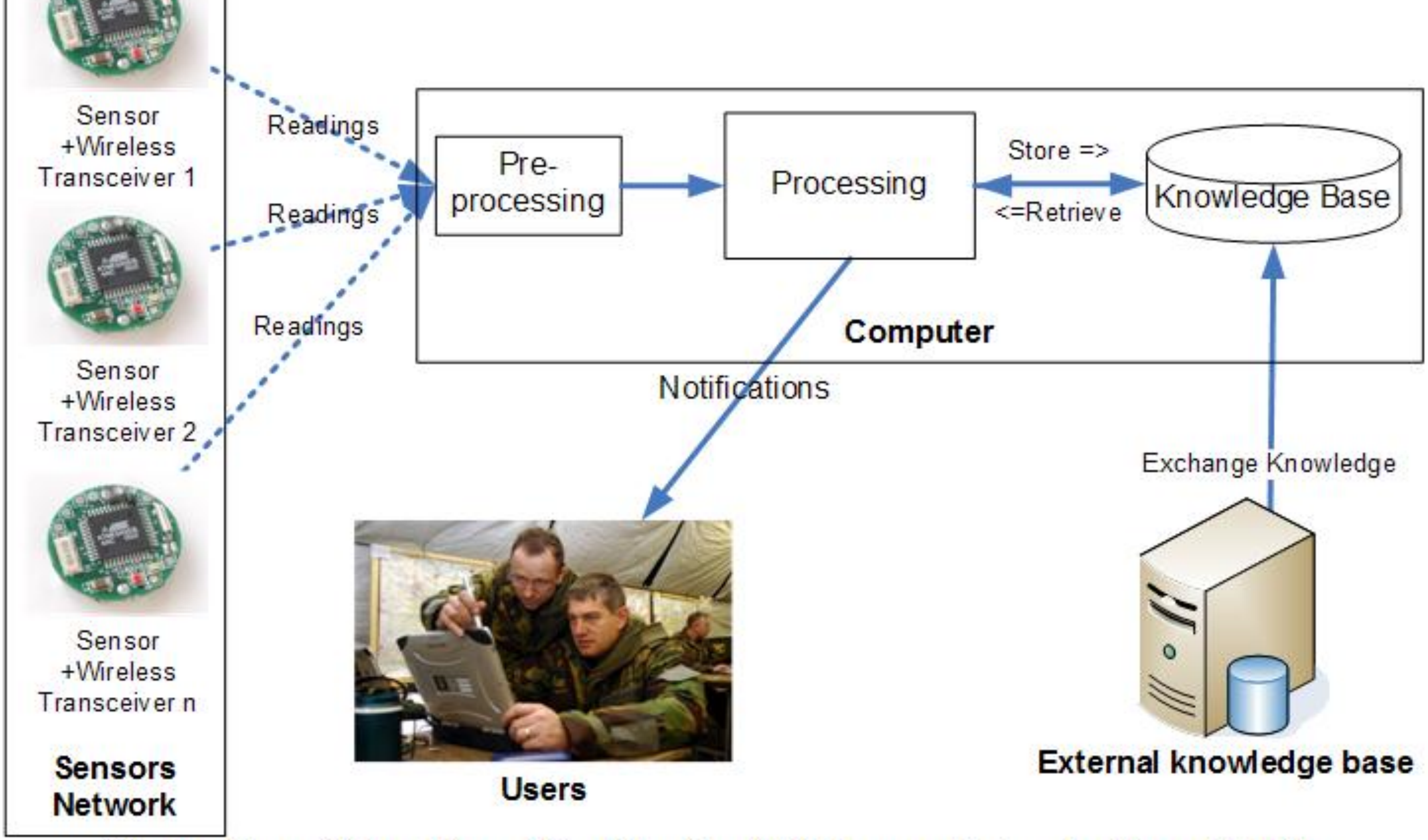
System Configuration



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

System Configuration

Can be extended to include automatic notifications and intelligent analysis modules



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

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 185ºF
- 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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