Tools for Sensor Performance Assessment

Research Assistants/Staff: *L. Jiang*

Faculty: *D. Djurdjanovic, J. Ni*

Objectives

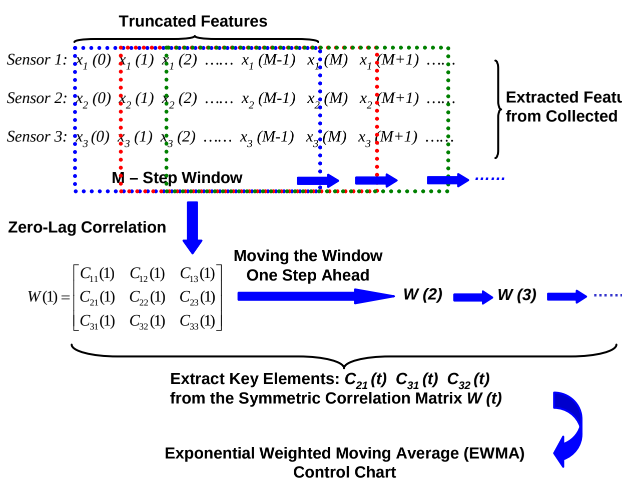
- To detect sensor progressive degradation and predict sensor failures and reconstruct the degrading sensor readings

State-of-the-Art

- *Direct hardware redundancy method*: use two or more sensors to measure the same key variable and assess sensor performance by comparing the consistency between different sensors, simple to implement but potentially costly
- *Functional redundancy method*: use multiple sensors to measure related variables and validate sensor readings by employing sensor fusion techniques, more complex but cheaper approach

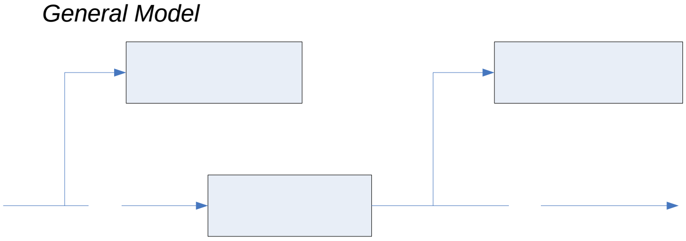
Approaches

- Zero-lag correlation based direct hardware redundancy method



- Time-series modeling based functional redundancy method

General Model



Transfer Function

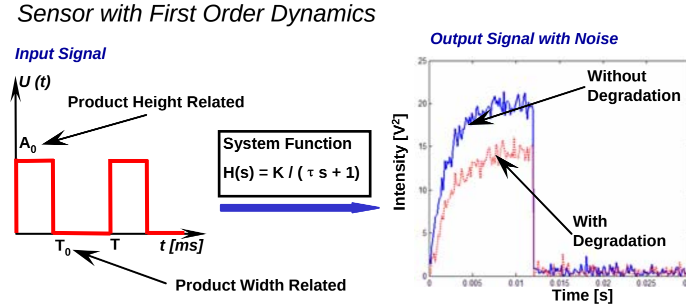
$$G(s) = \frac{S_1(s)}{S_2(s)} = \frac{G_0(s)G_{out}(s)}{G_{in}(s)} = \frac{A_0(s)A_{out}(s)B_{in}(s)}{B_0(s)B_{out}(s)A_{in}(s)}$$

Methods

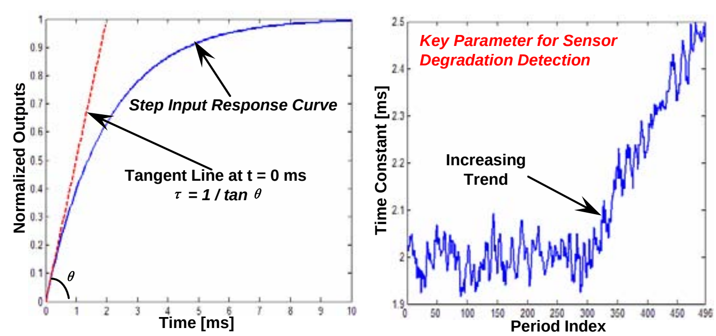
By fitting Auto-Regressive Moving Average Vector (ARMAV) time series model to the data within an extending window, the dynamics of the plant and input/output sensor can be identified by finding the zeros and poles of the transfer function.

Case Study

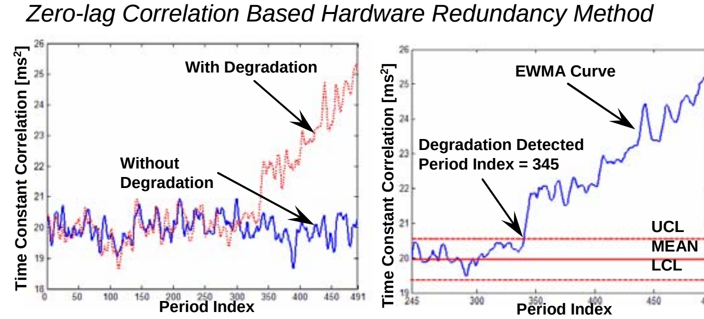
Sensor with First Order Dynamics



Feature Extraction



Zero-lag Correlation Based Hardware Redundancy Method



Future Work

- Evaluate both methods with real industrial data instead of simulation data
- Develop algorithm for sensor data reconstruction

For more information, contact Prof. J. Ni; Phone: 734-936-2918; Email: junni@umich.edu

Detection of Intermittent Connections in An Industrial Network

Research Assistants/Staff: *Y. Lei*

Faculty: *J. Ni, D. Djurdjanovic*

Objectives

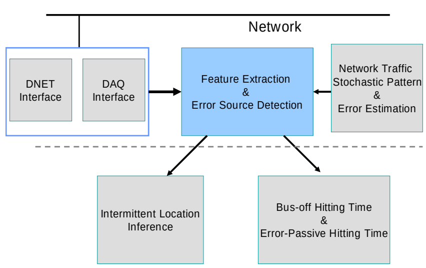
- Provide network performance and diagnostic information at the device level and network level.
- Develop novel network health monitoring tools for plant floor network systems.
- Minimize network diagnosing time due to intermittent connections on the network.

State-of-the-Art

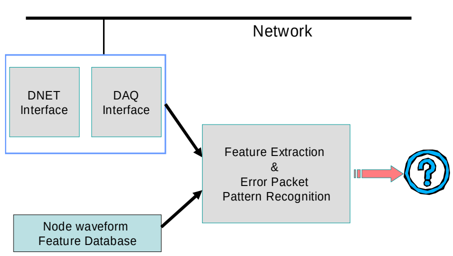
- Intermittent Connection is difficult to identify.
- No tool available for Intermittent Connection detection

Approaches

- Network health monitoring framework

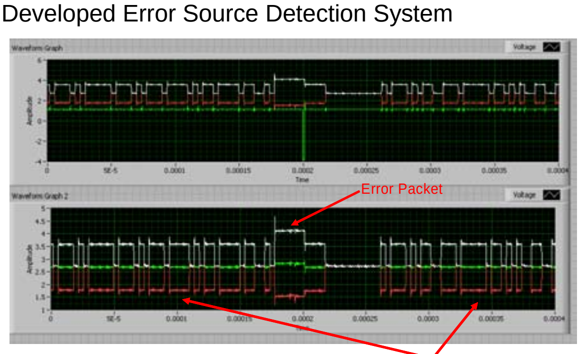


- Error Source Detection

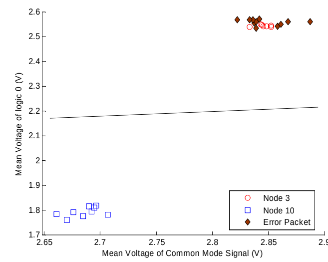


Accomplishments

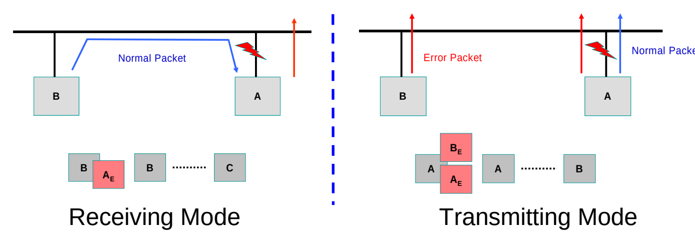
- Developed Error Source Detection System



- Classification Result of Error Source



- Identification of Error Location
  - Intermittent connection scenarios



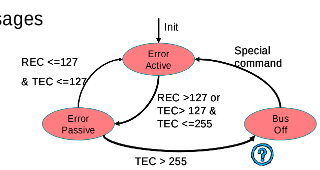
- Determination of the error location
  - Assume the intermittent connection locate at the drop cable of a node
  - If we observe two patterns happens coincidentally
    - Node A send error packet after normal packets
    - Error packets followed by packet sent by node A
  - Then Node A has intermittent connection problem.

- Network Node Health Modeling

$Q =$

	0	1	2	...	8	9	..	253	254	255	256
0	$-\lambda_1^k$	0	0	...	λ_1^k	0	..	0	0	0	0
1	λ_0^k	$-\lambda^k$	0	...	0	λ_1^k	..	0	0	0	0
2	0	λ_0^k	$-\lambda^k$	...	0	0	..	0	0	0	0
.	.	.	.	.	.	.	..	.	.	.	.
.	.	.	.	.	.	.	..	.	.	.	.
254	0	0	0	...	0	0	..	λ_0^k	$-\lambda^k$	0	λ_1^k
255	0	0	0	...	0	0	..	0	λ_0^k	$-\lambda^k$	λ_1^k
256	0	0	0	...	0	0	..	0	0	0	0

- λ_0^k is the rate of transmission of non-corrupted messages for station k
- λ_1^k is the rate of corrupted messages
- $\lambda^k = \lambda_0^k + \lambda_1^k$



Future Work

- Conduct plant validations
- Construct intermittent connection model and estimate nodes bus-off time

Sponsors

- NSF I/UCRC for Intelligent Maintenance Systems

For more information, contact Prof. J. Ni; Phone: 734-936-2918; Email: junni@umich.edu

Cutting Process Monitoring in Turbine Blade Machining

Research Assistants/Staff:
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Faculty:
D. Djurdjanovic, J. Ni

Objectives

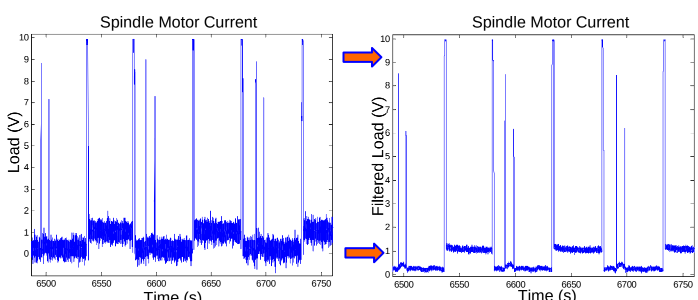
- Track 5-axis mill health under dynamically-varying, oblique loading conditions
- Improve tracking and prediction of process health for various machines through signal processing
- Propose a general method for tracking the health of a mill bit without adding sensors to the system
- Decrease the overall cost of milling compressor blades by using a condition-based method to change mill bits

State-of-the-Art

- Use only the load data (amount of current) from the spindle and 5 servo motor drives to track mill bit health
- Explore correlation between servo motor current and cutting force in an oblique cutting
- Employ Time Frequency Analysis and other recently-developed methods to extract features from load data.

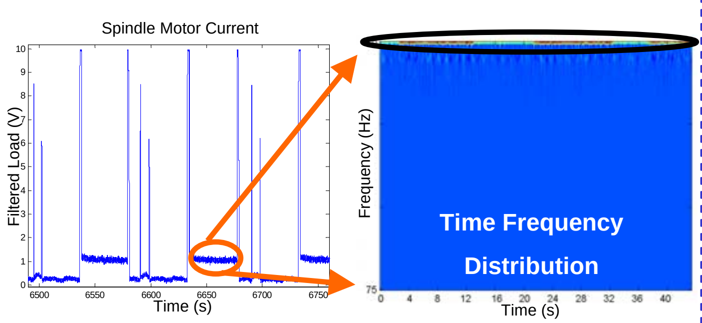
Approach

- Filter raw load data using low-pass filter



Effect of filtering on data.

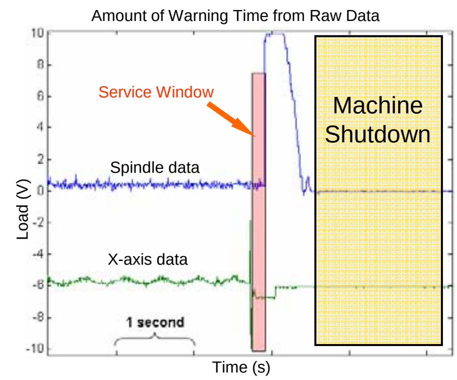
- Partition filtered data to separate milling passes based on varying levels in servo-motor current
- Extract features from filtered data using TFA



Extraction of features using Time Frequency Analysis

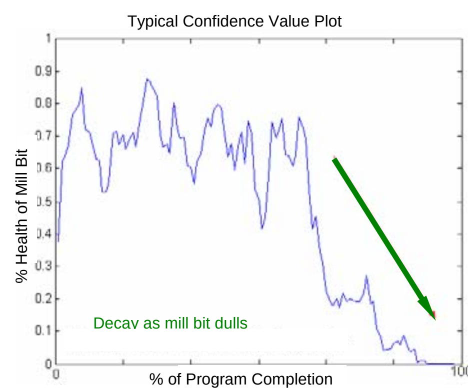
Accomplishments

- Provided warning time (based on raw data) before unexpected shutdown happens



Warning of shutdown based on level of X-axis signal

- Found method for properly partitioning data
- Determined predictive model for health of mill bit
- Produced CV degradation trends for load data



Decay of mill bit health based on drift of process features

Future Work

- Finish characterization of mill health
- Install sensors and begin collecting data on grinder
- Integrate and process data from multiple sensors with various frequency ranges for the grinder project

Sponsors

- This research is supported by General Electric Aviation. My contact at GE is Roger Lindle.

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Immune System Engineering for Automotive Systems

Research Assistants/Staff:
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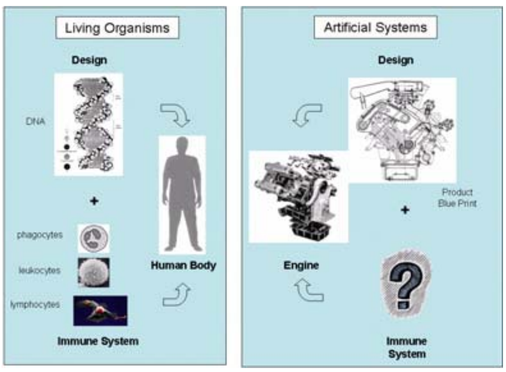
D. Djurdjanovic

Faculty:
J. Ni

Objectives

- Develop novel approach to realize "immune systems" functionalities in automated systems.
- Robustly detect abnormal behavior, isolate source, and compensate for negative effects to achieve desired performance in spite of the presence of an anomaly.

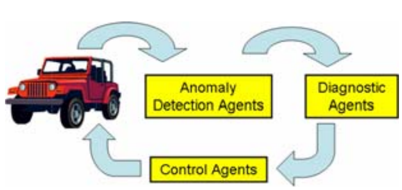


An anomaly effects automated system like a virus effects human

Problem Statement

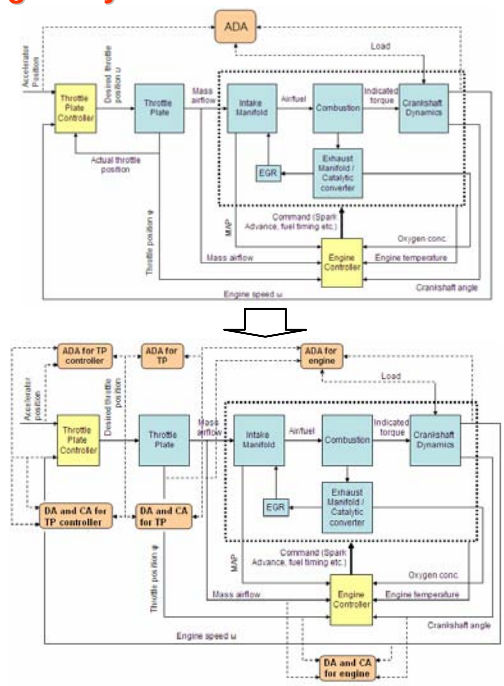
- The goal of the proposed research will be to incorporate the natural immune system functionalities and uniqueness into automotive engine system. There are three primary parts for accomplishing this target:

- Anomaly Detection Agents (ADA-s)
  - -Identify the intrusion depicted in the degraded system
  - -Isolate the intrusion source by reconfiguring, reconnecting and decomposing detection agents.
- Diagnostic Agents (DA-s)
  - -Recognize and describe the anomaly source character if input/ output patterns have been observed in the past.
  - -In case input/output patterns have not been seen in the past, create a new DA for recognizing the new anomaly next time.
- Control Agents (CA-s)
  - -Utilize fault characterization from DAs to postulate control laws for restoring the performance of the anomalous subsystem as much as possible.



Proposed immune system operation for an automotive system

Immune System for the Automotive Engine System



Multiplication of ADA-s, DA-s and CA-s in the electronic throttle mechanism

Proposed Research Task and Time Table

	Month					
Tasks	0-6	7-12	13-18	19-24	25-30	31-36
Task 1: Methods for Anomaly Detection and Isolation	←			→		
Subtask 1.1: Multi-regime anomaly detection						
Subtask 1.2: Isolation of the Anomaly Source						
Subtask 1.3: Practical implementation of ADA-s						
Task 2: Methods for Diagnosis of Anomalous Condition		←			→	
Subtask 2.1: Methods for realization of DA-s						
Subtask 2.2: Development of identification methods						
Subtask 2.3: Demonstration on an engine subsystem						
Task 3: Methods for Control System Reconfiguration			←			→
Subtask 3.1: Design of CA-s for recovering performance						
Subtask 3.2: Implementation on an engine subsystem						

The research activity for over a three-year period

Project Leadership and Management

- PI: Dr. Dragan Djurdjanovic, University of Michigan
- Co-PI: Prof. Jun Ni, University of Michigan
  Kenneth Marko, ETAS Inc

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