Detection, Isolation, and Recovery of Sensor Performance Degradation

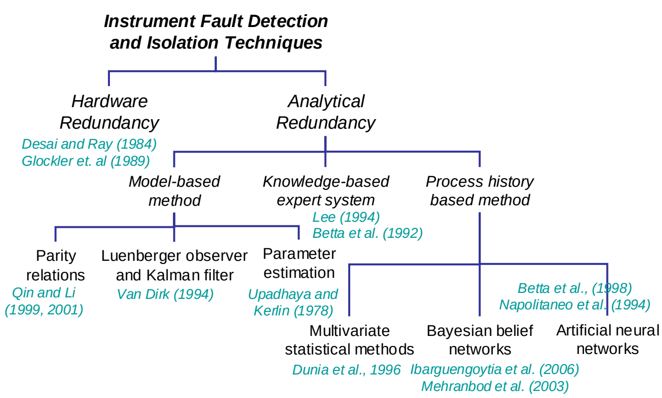
Research Assistants/Staff:
L. JIANG

Faculty:
D. Djurdjanovic, J. Ni

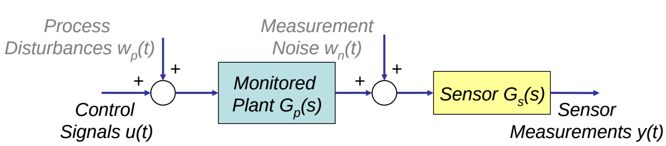
Objectives

- An ever-increasing number of sensors have been employed in dynamic systems to ensure correct control functionalities and diagnosis.
- Nevertheless, a sensor itself degrades and fails, just as any other dynamic system.
- A faulty sensor may cause undesirable system performance, process shut down, or even a fatal accident.

State-of-the-Art

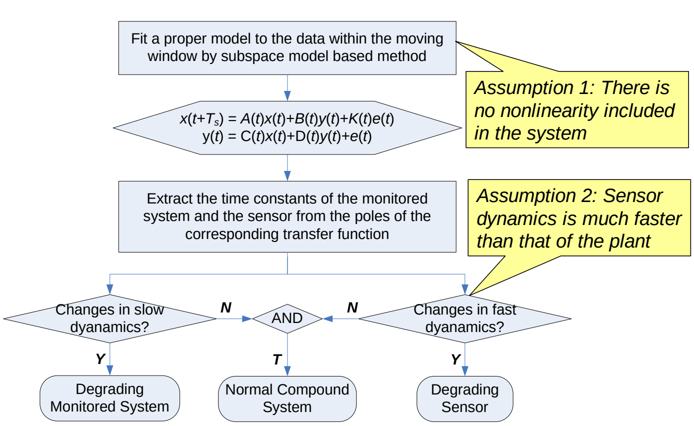


Approaches

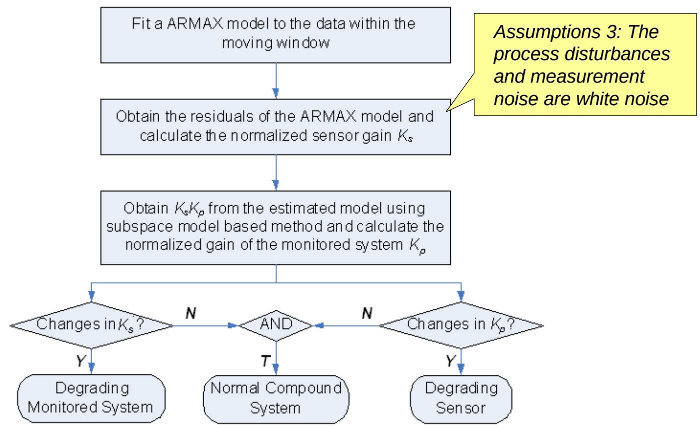


$$Y(s) = G_p G_s (U(s) + W_p(s)) + G_s W_n(s)$$

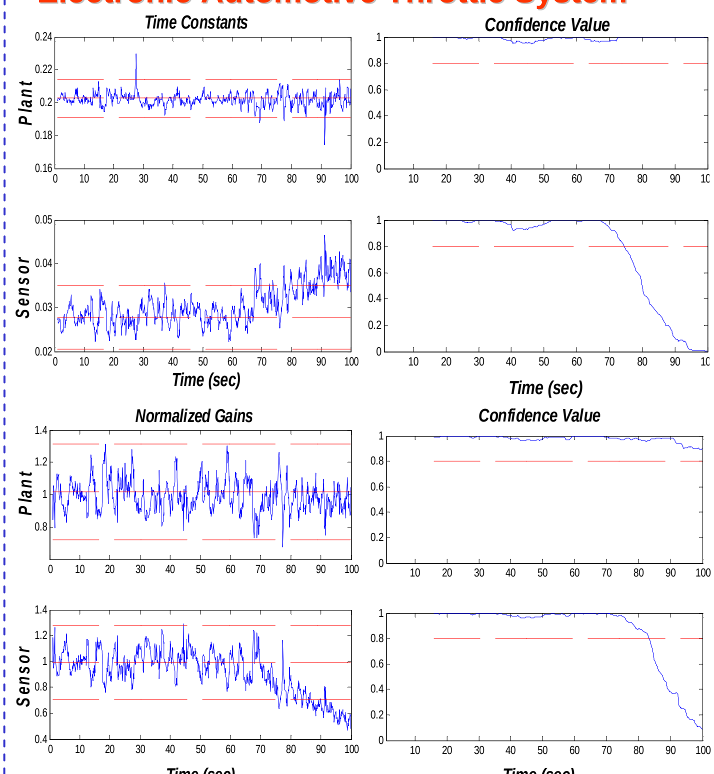
Detection and Isolation of Dynamic Changes



Detection and Isolation of Gain Changes



Electronic Automotive Throttle System



Future Work

- Develop methods for the case when the process disturbances and measurement noise are colored noise processes.
- Extend this method to detect and isolation degraded sensors in presence of nonlinearities in the monitored system

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

A Watchdog Agent™ Toolbox for Multisensor Performance Assessment

Research Assistants/Staff:
K. Johnson

Faculty:
D. Djurdjanovic, J. Ni

Objectives

- The Watchdog Agent™ Toolbox is a software program that has been created to assess and predict system performance in various conditions and easily assess which combination of algorithms is the best fit for a particular application.

State-of-the-Art

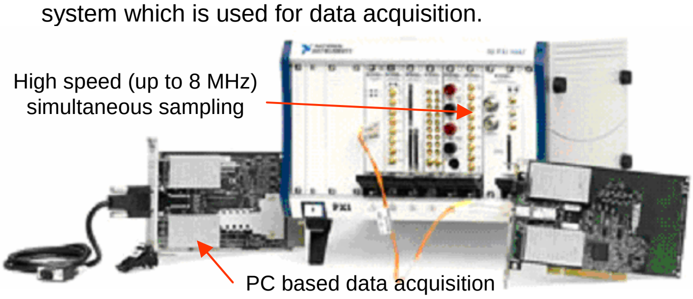
- Modularization of the toolbox allows different methods of signal processing, feature extraction, performance evaluation, and sensor fusion to be used in any combination.

Approaches

- The software takes as input sensor data from the current, normal, and faulty operation of the equipment, and outputs the current level of degradation of the system, an ARMA prediction of future degradation, and a sensitivity analysis, or measure of affinity, for the chosen algorithms.
- The Watchdog Agent™ Toolbox has several functional layers, shown below, compliant with the Open System Architecture for Condition Based Maintenance (OSA-CBM).

Data Acquisition	National Instruments PXI system
Data Manipulation	Time frequency, wavelet, FFT analysis
Condition Monitor	Not currently integrated
Health Assessment	Statistical pattern recognition, logistic regression, sensor fusion
Prognostics	ARMA modeling
Decision Support	Not currently integrated
Presentation	Graphical user interface (GUI)

- The following picture shows the National Instruments PXI system which is used for data acquisition.

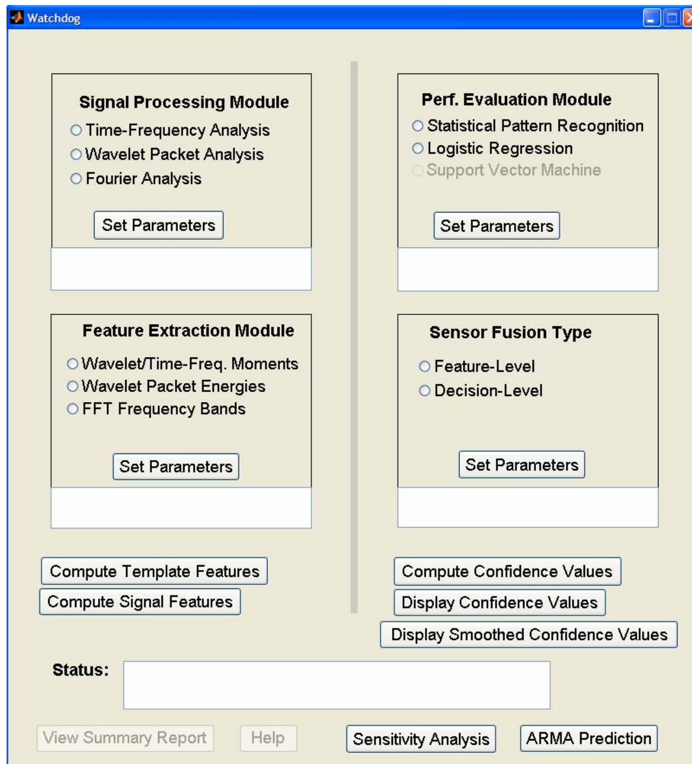


Sponsors

- NSF Industry/University Collaborative Research Center on Intelligent Maintenance Systems
- National Instruments

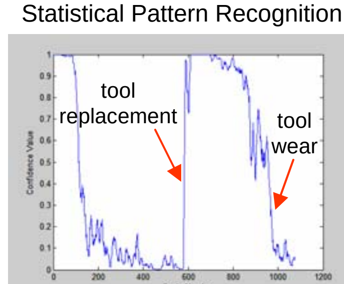
Accomplishments

- Several interchangeable tools have been developed in Matlab and compiled into a standalone application. The tools that have been integrated can be seen below in the main window of the Watchdog Agent™ Toolbox.

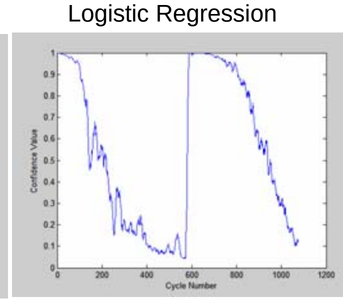


- Shown below is the degradation analysis from 1100 cycles of a boring tool at DaimlerChrysler; two methods of performance assessment are compared.

Statistical Pattern Recognition



Logistic Regression



Future Work

- A method for analysis of discrete event data will be added to the toolbox.

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

Embedded Watchdog Agent™ for Industrial Automation Systems

Research Assistants/Staff: *Y. Lei*

Faculty: *D. Djudjanovic, J. Ni*

Objectives

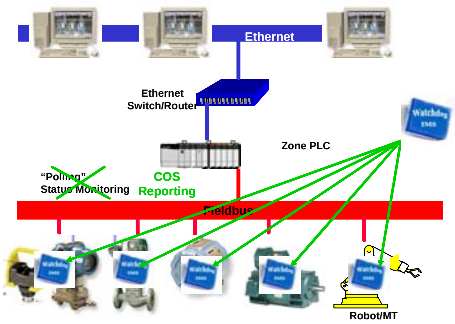
- Provide diagnostic & predictive information in a networked industrial automation system at the device level.
- Develop a methodology to evaluate effects of device-level embedded prognostics
- Create methods to minimize maintenance-related costs through strategic allocation of failure risks associated with basic embedded prognostics.

State-of-the-Art

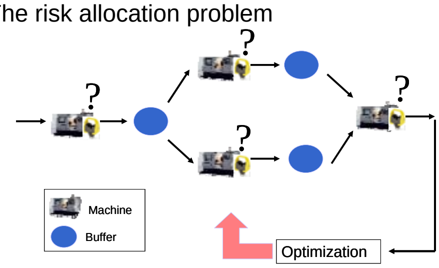
- Due to bandwidth limitations, limited amount of maintenance related information is available in an industrial networked automation systems.
- Inherent intelligence of networked devices is not utilized for maintenance purposes.

Approaches

- The Embedded Watchdog Agent™ solution



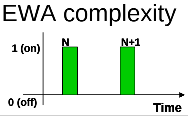
- The risk allocation problem



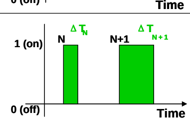
Accomplishments

- Defined 3 levels of EWA complexity

Level 1: Operation/cycle counter

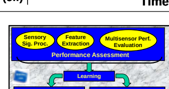


Level 2: Operation/cycle counter AND Cycle Timer



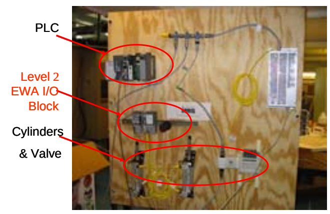
Basic Prognostics

Level 3: Trending and data streaming

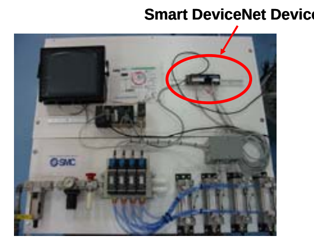


Advanced Prognostics

- Built two testbeds for verification and demonstration of effects and benefits of the basic prognostics in Embedded Watchdog Agent

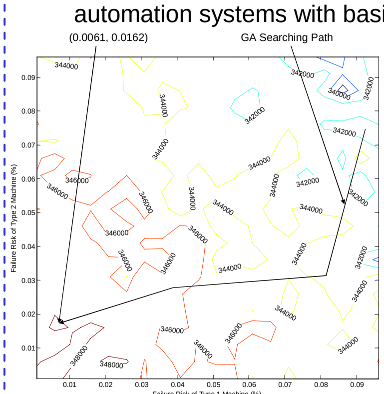


Level 1 & 2 EWA Testbed Sponsored By Rockwell Automation and GM

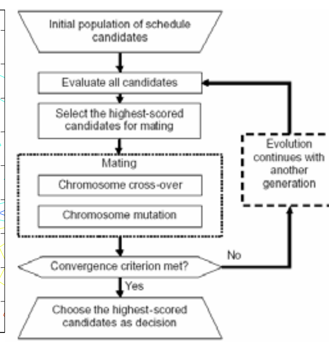


Smart DeviceNet Device Testbed Sponsored By Omron

- Developed a risk allocation methodology for industrial automation systems with basic prognostics

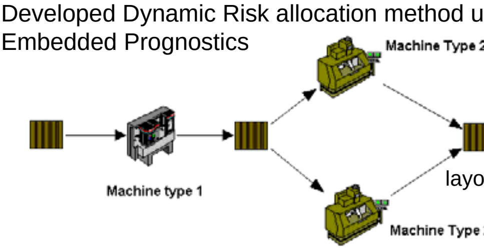


Risk Allocation of Risks of Failure Using Genetic Algorithm



Flowchart for optimal risk allocation based on a Genetic Algorithm

- Developed Dynamic Risk allocation method using Basic Embedded Prognostics



layout of the system considered

Table: Risk levels assigned to machines of Type 1 & Type 2

Scenarios	Type 1 Machine	Type 2 Machines
(1) All machines are working	0.0061	0.0162
(2) One of the type 2 machines is broken-down	0.0103	0.0198

	Combined Benefit (Monetary Unit)
Dynamic Risk Allocation	1765.59 ± 3.8
Static Risk Allocation	1753.84 ± 4.0

Future Work

- Conduct and improve dynamic optimal risk allocation using Basic Embedded Watchdog Agent™ Prognostics in complex industrial automation systems.
- Conduct industrial test and cost effect analysis of basic prognostics Embedded Watchdog Agent™.

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

Network Watchdog Agent™ for Industrial Automation Systems

Research Assistants/Staff:
Y. Lei

Faculty:
D. Djudjanovic, J. Ni

Motivation

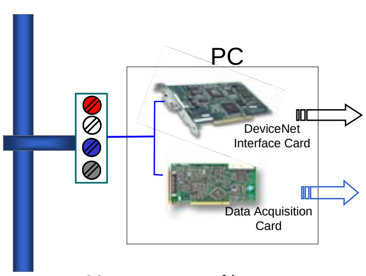
- Nearly 54% of failures in a networked industrial automation system occur due to faults on the network itself.
- There is need to create a predictive agent for assessment and prediction of performance of an industrial automation network.
- Current tools are not designed to provide such capabilities

Objectives

- Develop and evaluate novel network health monitoring tools for industrial automation systems
- Develop methodology that could assess and predict the performance of industrial automation networks.

Approaches

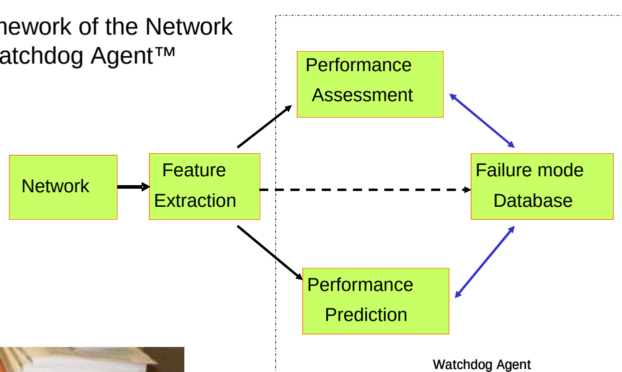
- Proposed data acquisition system



Statistic Data
Error Frame Ratio
Bus load
Bus Voltage
Overshoot
Signal-To-Noise Ratio

Measurement of key parameters of DeviceNet

Framework of the Network Watchdog Agent™

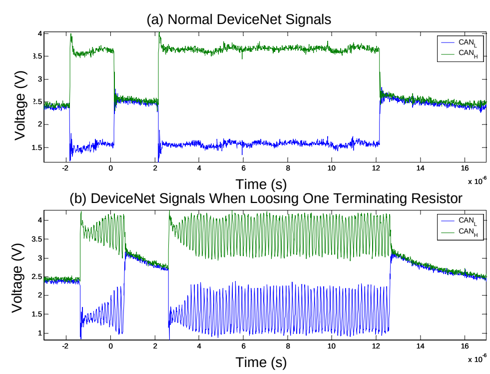


Data collection system

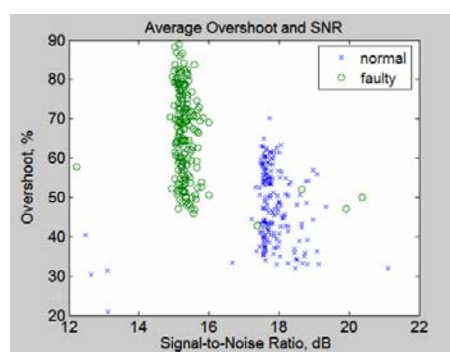
- National instruments digital oscilloscope
- SST DeviceNet interface card

Accomplishments

- Identified key failure modes that occur in the networked industrial automation systems
  - Connection problems, including loose connection of cable connectors and terminating resistors
  - Corrupt frames, including damaged transceivers, grounding problems, electrical Magnetic Interference (EMI)
- Identified key parameters that affect the performance of networked industrial automation systems
  - Bus voltage and current
  - Common Mode Signal features
  - Waveform of Digital signal
- Preliminary results of one lost terminating resistor



Comparison of DeviceNet signals under normal condition and with one lost terminating resistor



Feature cluster under normal condition and with one lost terminating resistor

Future Work

- Develop NWA for the data link layer
- Develop diagnosis methodology using data from both data link layer and physical layer
- Testbed validation and demonstration for NWA.

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

Anomaly Detection and Localization for Dynamic Control System

Research Assistants/Staff: J. Liu

Faculty: J. Ni

Objectives

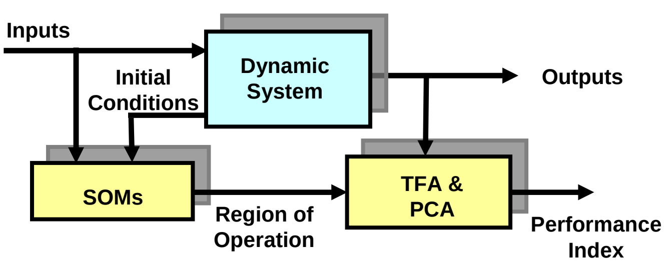
- Detecting and localizing unknown faults i.e. anomalies
- Sensing gradual performance degradation of controlled dynamic system
- Discriminating whether the performance deviation is caused by control software or plant (hardware)
- Developing effective diagnostics that can be applied comprehensively from product design through design validation, manufacturing testing on-board monitoring and finally repair service operating

State-of-the-Art

- With the growing complexity of both plants and control systems, effective diagnostics for all possible failures has become increasingly difficult and time consuming.
- As a result, many systems rely on limited diagnostic coverage provided by a diagnostic strategy which test only for known or anticipated failures, and presumes the system is operating normally if the full set of tests is passed.
- In addition, these tests are often developed separately and at large costs in terms of time and resources after hardware and the control system have been produced and are available for analysis.

Approaches

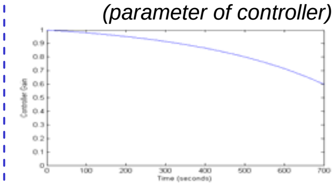
➢ *Method Overview*



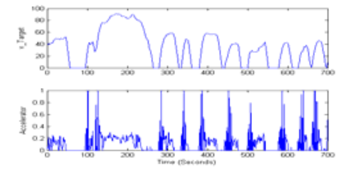
- The new anomaly detection method relies on the use of Self-Organizing Maps (SOM) for regionalization of the system operating conditions, followed by Time-Frequency Analysis (TFA) and Principal Component Analysis (PCA) for anomaly detection and fault isolation
- The proposed approach consists of two elements: *anomaly detection* which identifies whether a deviation from normal operation has occurred and *fault isolation*, which isolates the problem, as best as possible, to the specific component or subsystem that has failed.

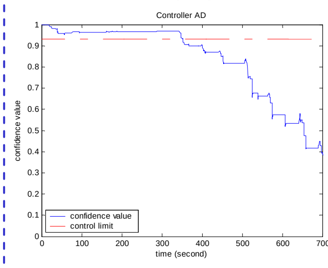
➢ *Anomaly Detection and Localization*

Gradual decrease in the gain factor (parameter of controller)

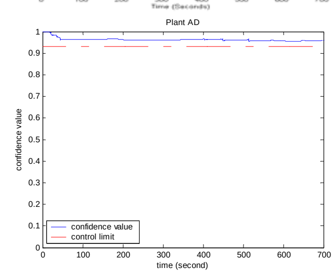


Driving Profile:FTP75





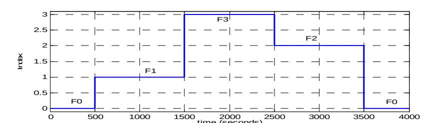
AD on controller

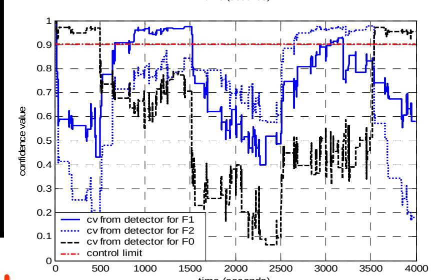


AD on plant

➢ *Fault isolation*

Index	Category
F0	Normal
F1	Reduced *K*
F2	Increased *C*
F3	A unknown fault





Accomplishments

- Ability to detect gradual changes of the system parameters as the dynamic system operates.
- Ability to detect faults that were not observed before (i.e. detect anomalies) using the same generic approach.
- No prior assumptions were made about the system behavior and the model of system behavior was learnt from a normal driving profile.
- Ability to detect and isolate of controller (software) anomalies from the plant (hardware) anomalies.

Future Work

- Development of effective method for intermittent fault detection

Sponsors

- This project is supported in part by Center for Intelligent Maintenance System at University of Michigan, Ann Arbor and ETAS Inc., Ann Arbor

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

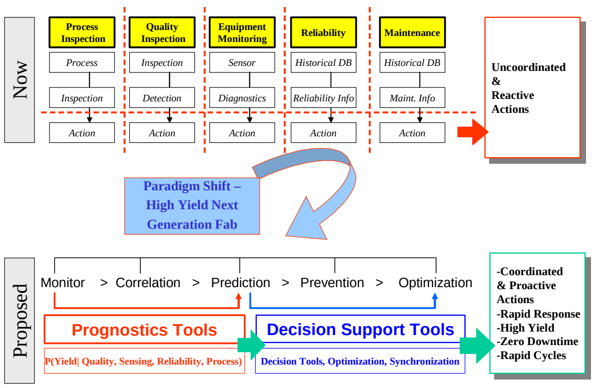
Data Fusion and Predictive Modeling for Intelligent Maintenance in Complex Semiconductor Manufacturing Processes

Research Assistants/Staff: *Y. Liu*

Faculty: *J. Ni, D. Djurdjanovic*

Objectives

- To develop system modeling and decision support tools that integrate different data domains in a semiconductor fabrication facility into coherent performance information that will facilitate rapid and proactive countermeasures for any problem that will adversely affect the yield and uptime
- To coordinate and synthesize the integrated information from all stations into system level information that will be used to make dynamic, accurate and cost-effective maintenance scheduling and product routing decisions



State-of-the-Art

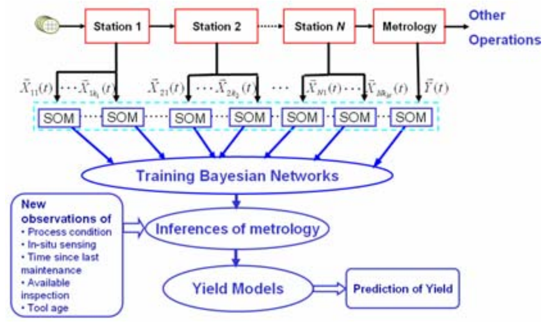
- Many yield models based on defect detection and critical area analysis have been developed, in which, however, only defect inspection data are utilized
- Researchers have attempted to predict yield using localized in-line data or in-situ measurements of particle contamination, which only give a partial picture of the process degradation
- Majority of maintenance operations are still based on either historical reliability of equipment, or diagnostic information from equipment performance signatures extracted from in-situ sensors

Approaches

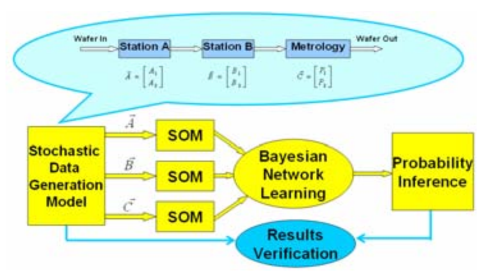
- Improved yield prediction from integrated information flow using enhanced Bayesian networks
- Enhanced maintenance decision support tools based on improved yield estimation model
- Validation of results in an industrial testbed

Accomplishments

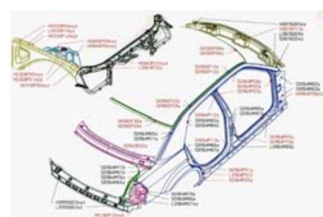
- Framework for data integration and probability inference

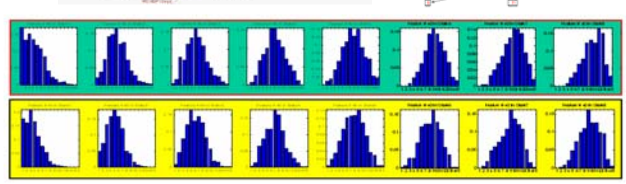


- Simulation study to validate the proposed method



- Application to automotive industry dataset





State of Feature # 40	1	2	3	4	5	6	7	8	9	10	11	12	13
Number of Evidence	1857	924	1017	668	512	397	387	327	246	239	197	95	114
Euclidean Distance (Feature # 8)	0.0867	0.1219	0.0915	0.0900	0.0904	0.0942	0.0830	0.1248	0.1158	0.1326	0.1241	0.1439	0.4715
Euclidean Distance (Feature # 11)	0.0490	0.0529	0.0471	0.0588	0.0661	0.0636	0.0618	0.0810	0.0930	0.1156	0.1391	0.1163	0.2322

Future Work

- Performing case study using semiconductor dataset
- Handling incomplete data without compromising inference accuracy
- Periodically updating inference structure when real inspection becomes available

Sponsors

Semiconductor Research Corporation (SRC)

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

Embedded Life Cycle Unit for Prognostics of Mechanical Systems

Research Assistants/Staff: R. Muminovic

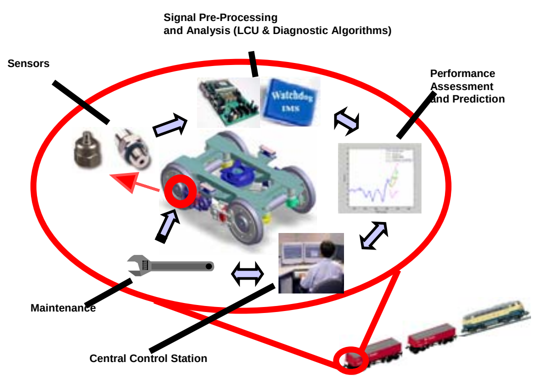
Faculty: Dr. D. Djurdjanovic / Prof. J. Ni

Objectives

- Shift the maintenance policy from reactive to proactive
- Assess current performance of a railroad bogie bearing

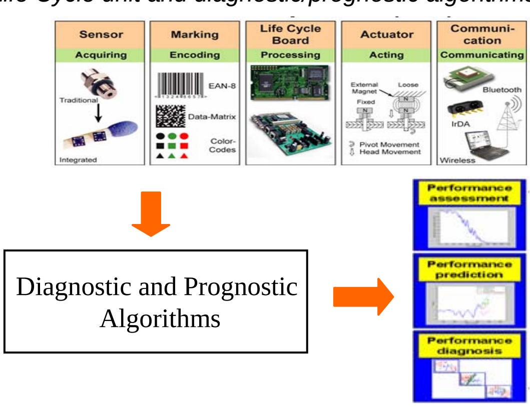
Condition Based Maintenance

❖*Condition based maintenance policy*



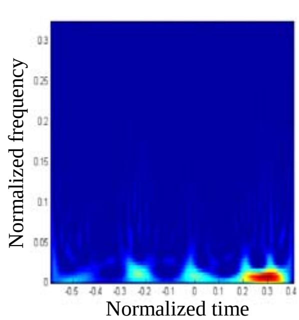
Approach

❖*Life Cycle unit and diagnostic/prognostic algorithms*



❖*Feature extraction – Time-frequency distribution*

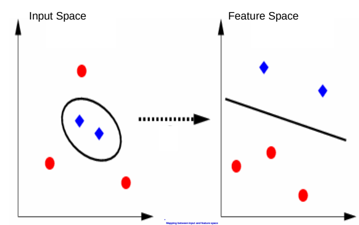
- Time-frequency representation is a view of a signal represented over both time and frequency.
- Time-frequency analysis is particularly suitable for nonstationary signals whose frequency content varies over time



Classification Method

❖*Support Vector Machine (SVM)*

- Training vectors are mapped into a higher dimensional space with help of a kernel
- SVM algorithm creates a maximum-margin hyperplane that separates data into two classes

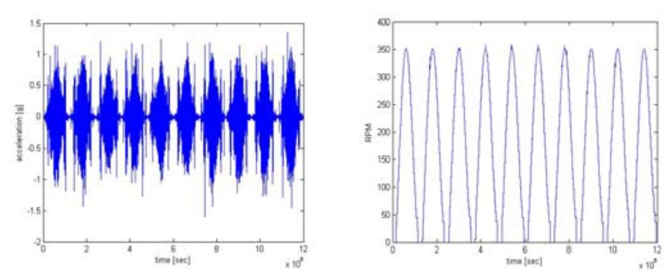


Measurement

❖*Testbed*

- RPM was varied with a sinusoidal input
- Sinusoid has a period of T=60s
- Experiment was conducted with five different loads acting on the bogie cage

❖*Measured vibrations*



Expected Results

- High identification rate of functional and defective bearing
- Improved maintenance policy through condition based maintenance

For more information, contact:

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Immune Systems Engineering for Complex Dynamic Systems

Research Assistants/Staff:
R. Torres
D. Djurdjanovic

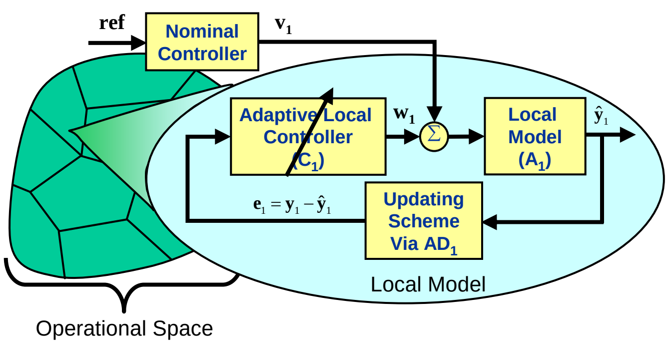
Faculty:
J. Ni

Objectives

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

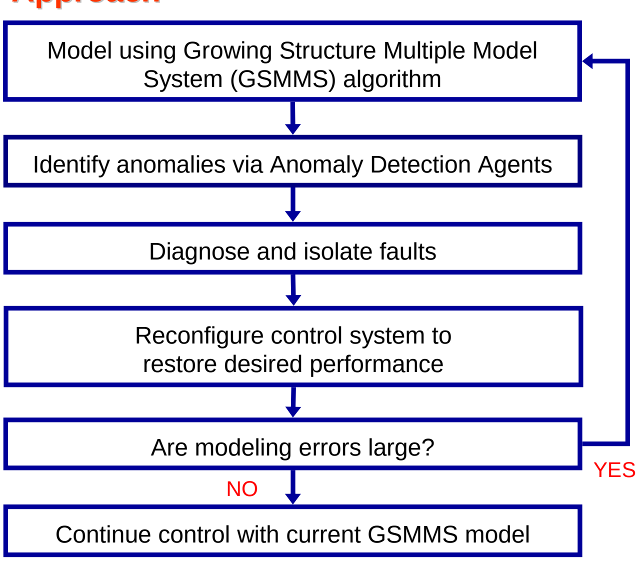
State-of-the-Art

- Nonlinear plant is regionalized into several local linear models through "divide and conquer" methodology
- Local models are analyzed for fault detection and isolation
- Adaptive local controllers are applied per region to achieve desired performance



Local Linear Models of Nonlinear System

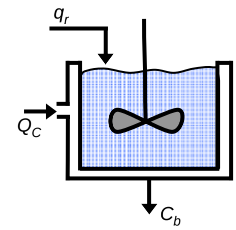
Approach



Accomplishments

Benchmark Problem

- Continuously Stir Tank Reactor (CSTR) Model is used to serve as the plant for preliminary study
- Inputs (flow rate, q_r and heat transfer removal rate, Q_C) are used to control output (concentration C_b)



CSTR Schematic

Modeling Results

- Recursive Learning for both GSMMS and Fuzzy Logic have been performed on CSTR model
- The index, *variance accounted for* (VAF), has been used to quantify the deviation of the models from the actual plant

  (Note: the VAF of two equal signals is 100%)

Comparison of Results

GSMMS

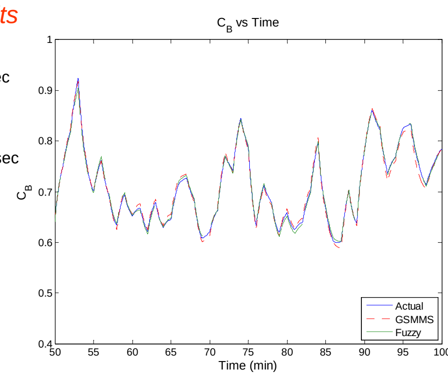
Computation Time = 2.01 sec

VAF = 99.1833 %

Fuzzy

Computation Time = 29.87 sec

VAF = 99.7115 %



Results using GSMMS and Fuzzy

Future Work

- Apply local adaptive controller to the local models
- Vary parameters to simulate anomalies
- Achieve desired performance despite anomalies
- Apply same approach to practical data (i.e. automotive engine)

Sponsors

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