ISRCS 2008

Trends in Control Systems

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Next Generation: Control Systems Frame Work

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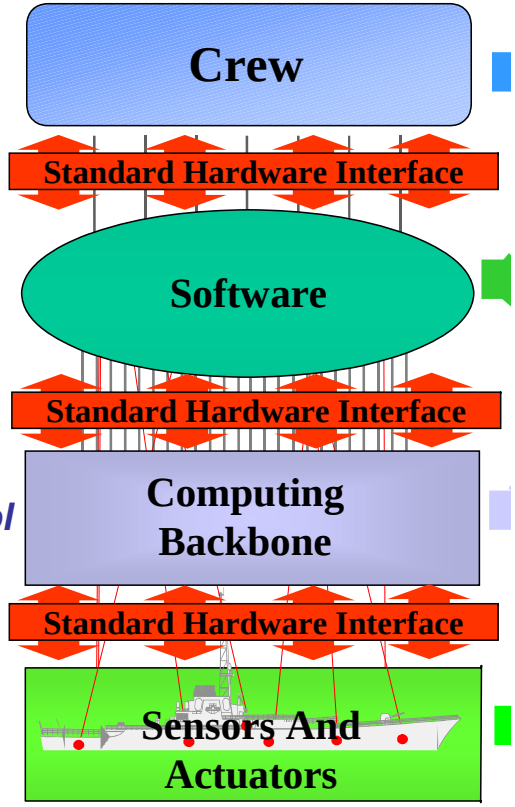
Systems Engineering Approach - Horizontal Abstraction

- **Establish a 'Systems of Systems' Naval Machinery Automation Architecture**
- **Abstract common Physical Functional Layers**
  - *Horizontal vice Vertical perspective*
  - *Impact of changes minimized between layers through the use of Standard Interfaces*
- **S&T targeted at these layers**
  - *Crew Interface*
  - *A Total Ship Software Architecture*
  - *A Total Ship Computing Plant Architecture*
  - *A Total Ship Machinery Monitoring and Control Architecture*
- **Vertical Transparency**
  - *No architectural boundary to prevent subscription to any data/information that is being acquired by any existing ship system*



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33 - Sea Warfare & Weapons S&T

Distributed Intelligence For Automated Survivability - Model Based Autonomy

Predictive Analysis

Objective

Investigate the use of Model Based Autonomy (MBA) to perform online, real-time diagnosis and reconfiguration

Performer

Dr. Dennis Lucarelli, Dr. Michael Miller, Mr. David Scheidt - Johns Hopkins University Applied Physics Laboratory

Dr. Brian Williams, Dr. Paul Robertson, Mr. Paul Elliott - Massachusetts Institute of Technology

Accomplishments FY07:

- **Deterministic Decomposable Negation Normal Form (DDNF) Based Belief State Estimation Algorithm**
  - Combines the polynomial time bound of the Model Executive (MEXEC) algorithm with the accuracy of the Best First Belief State Update algorithm
- **Investigations of MBA application to mixed, interdependent fluid and electrical distribution systems**
- **Revision of representational models to remedy limitations of previous models**
- **Implementation of Titan – next generation Model Based Reasoning Engine into the agent based control architecture**

Approach

Machinery Control System Methodology

Reasoning Engine – Model Based Agents

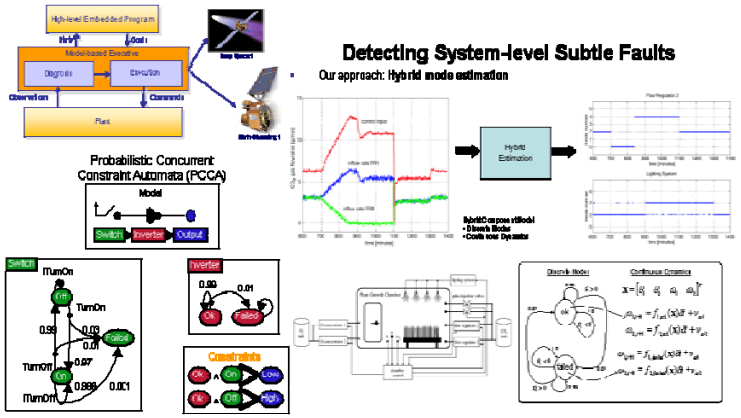
- Determine the current, partially hidden state of a system
- Estimator infers state by reasoning over :
  - *Sensory observations/ Commands executed/ Model of system dynamics*

System Model

- Defined state spaces
- Allowable transitions
- Transitions assigned probabilities - *Probability matrix as model representation*

- Model treated as a Hidden Markov Model (HMM)
  - Markov modeling : Transition from current state is not dependent on the previous state
  - HMM - Not all states are observable

- Overall framework for diagnosis, execution and repair: **Model-based programming**



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Applied Cluster-based Reconfiguration

Control Systems

Rockwell Automation

Objective

Investigate an approach to create agent control clusters targeted at the domain of shipboard auxiliary systems control

Performer

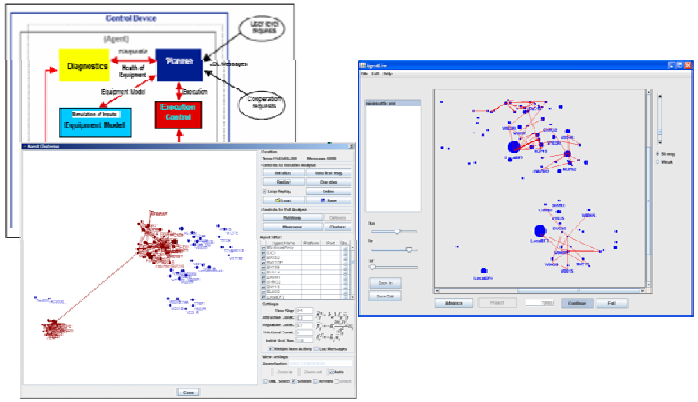
Dr. Francisco P. Maturana - Rockwell Automation Advanced Technology Laboratory

Accomplishments FY07

- Identified potential clusters of control agents
- Established mission priorities for clusters of control
- Investigation of heterogeneous agent interaction ontology and JDL syntax
- Agent clustering concept proven

Approach

- Explore the utilization of agent clusters to improve the efficiency of agent communications
- Explore the utilization of agent clusters to improve the design of agent based control systems
- Incorporate agent based control system on tabletop demonstrator for evaluation



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Advanced Hardware in the Loop Test Bed for Agent Based Control – The Tabletop

Systems Modeling

NAVSEA PHILADELPHIA

Objective

Develop a reduced scale demonstrator to provide a test bed for advanced control algorithms with hardware in-the-loop feedback to simulation

Performer

Mr. Frank Ferrese – Naval Surface Warfare Center, Philadelphia

Accomplishments FY07

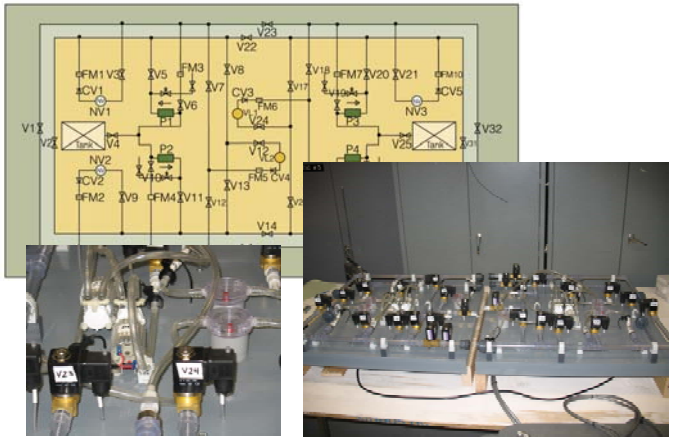
Modeled Two Zone Fluid, Electrical and Thermal shipboard distributed system - Provides 'real physics' feedback to larger simulations

Developed the design and constructed the model components of the demonstrator

- **Piping**
- **Remote control valves**
- **Pumps**
- **Reservoirs**
- **DC power supplies (ships service)**
- **Relays (switchboards)**

Approach

- **Common challenge problem platform - Multi-Institutional use**
- **Portability –It is portable enough so that it can be easily carried to different locations**
- **Flexibility - Supports multiple approaches for control (e.g., various agent topologies and reasoning algorithms)**
- **Complexity – Can Exhibit sufficiently challenging (nontrivial) scenarios/configurations**



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Exploration Of Evolutionary Algorithms For Automated Testing And Design Of Shipboard Chilled Water Systems

Design Optimization

Objective

Identify and investigate issues arising from the use of co-evolutionary algorithms to explore design spaces for naval machinery systems

Performer

Dr. Paolo Gaudiano - Icosystem Corporation

Dr. Elena Popovici - Icosystem Corporation

Accomplishments FY07

Applied co-evolution to the target domain of a firemain system containing smart valves.

Identified issues of cycling and loss of gradient

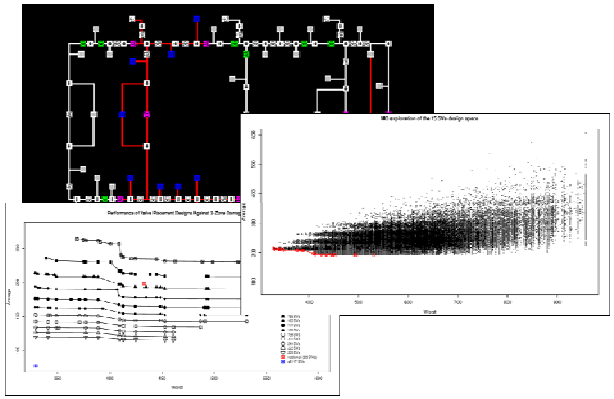
Investigated methods to resolve these issues

Approach

Develop a Genetic Algorithm to modify the design of a fluid system. The fitness function for this GA is to maximize the capability of the system after damage.

Develop a second GA to damage the system in a bounded manner. The fitness function for this system is to minimize the capability of the systems after damage.

Allow the two GA's to co-evolve, resulting in an optimal fluid system design.



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Market-based Resource Allocation in a Wirelessly Integrated Naval Engineering Plant

Situational Awareness

Objective

Investigate and demonstrate embedded computing, distributed computation, and flexible agent-based resource allocation in wireless sensor networks

Performer

Dr. Jerome P. Lynch – University of Michigan

Andrew Zimmerman – University of Michigan

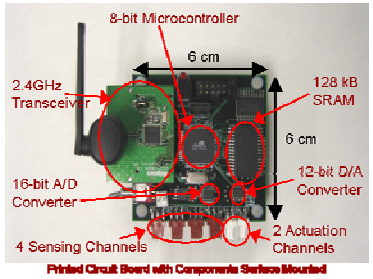
Accomplishments

- **Developed model based optimization (speed of processing, power mitigation) of distributed computing on wireless sensor nodes**
  - Embedment of *Simulated Annealing* Search Algorithm for Model Updating
  - Tested algorithms with n-Queens problem to determine system, model performance
  - Demonstrated real-time state awareness of wireless sensor nodes
  - Demonstrated self-healing, agile wireless sensor network
  - Real Time Closed Loop Control using wireless sensor nodes
- **Developed Pareto Optimal Resource Allocation Algorithms based On A Free Market Model**
  - Development of "market-based" demand functions for computational wireless sensor nodes (method by which optimization takes place)

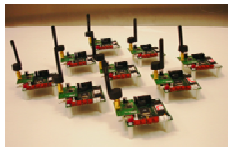
Approach

- **Designed a low-cost wireless node capable of both sensing and actuation**
  - Collocation of computing with sensing and actuation
- **Real-time machinery plant health and situation awareness**
- **Ad-hoc MESH network and agent interaction between wireless nodes**
- **Market based algorithms to optimally assign computing resources**
- **Distribute computing resources between multiple tasks in a distributed architecture**
- **Real-time, adaptive, decentralized control of distributed naval machinery plants**

- **Wireless sensor based on COTS technology:**
  - **16-bit ADC resolution**
  - **IEEE802.15.4 radio stacked upon main PCB**
  - **Actuation on 2-channels**



Printed Circuit Board with Components Surface Mounted



Combined Wireless Sensor Network

Performance Specification	
Cost	$175 per unit
Form Factor	8 cm x 6 cm x 2 cm
Energy Source	5 AA Batteries
Power	45 mA@5V
Range	50 m
Data Rate	250 Kbps
Sample Rate	100 kHz

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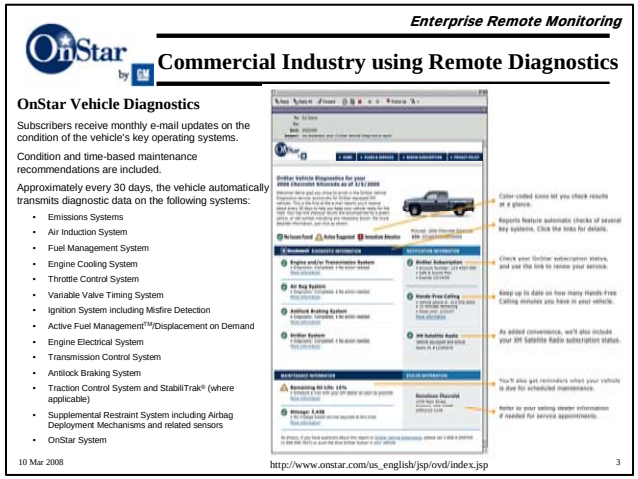
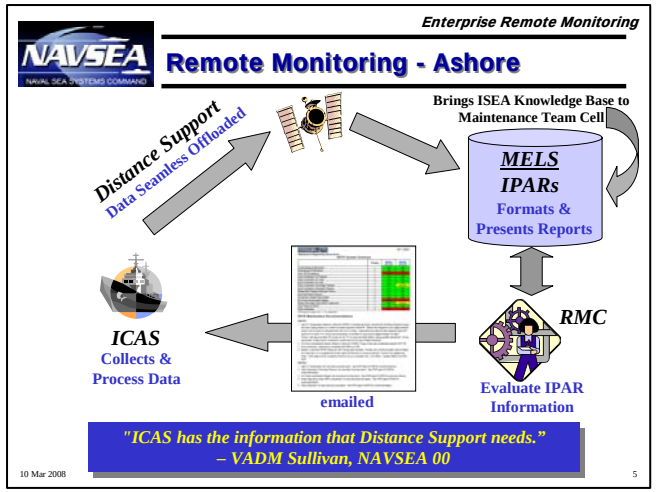
Next Generation: Remote Monitoring



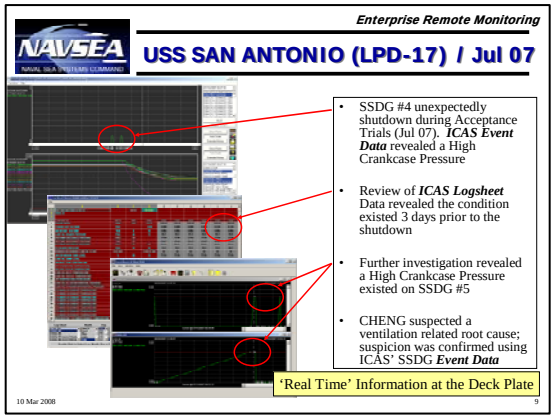
Commercial Remote Diagnostics

- **GE**: Gas Turbines/Diesels
- **Caterpillar**: Diesels
- **GM**: On Star



NAVY Remote Diagnostics

- Gas Turbines
- Diesel
- One way data push



Next Generation Remote Monitoring & Control Requires: Bi-Directional/ Firewall Capability