Integrated Industrial Process Sensing and Control System Applied to and Demonstrated on Cupola Furnaces

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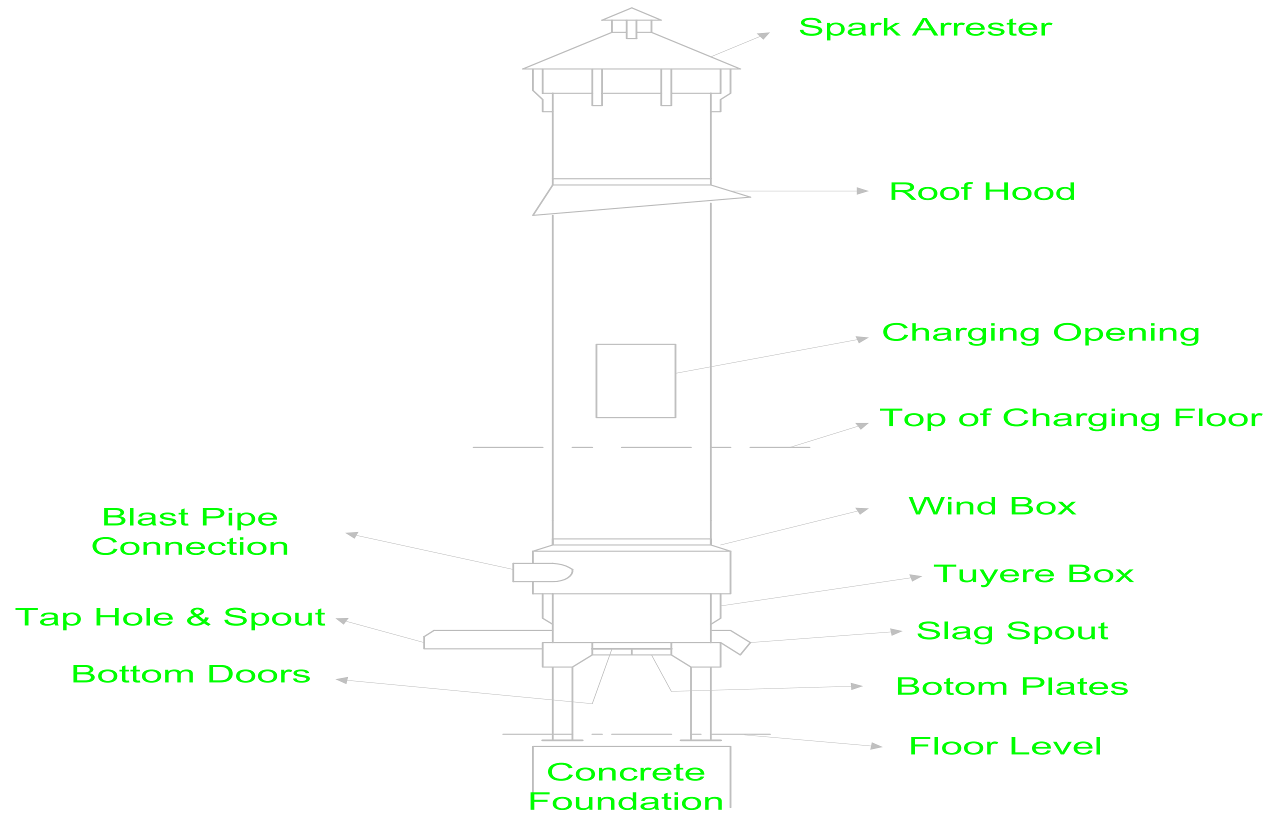
  - Hardware Implementation

Cupola Iron-Melting Furnace



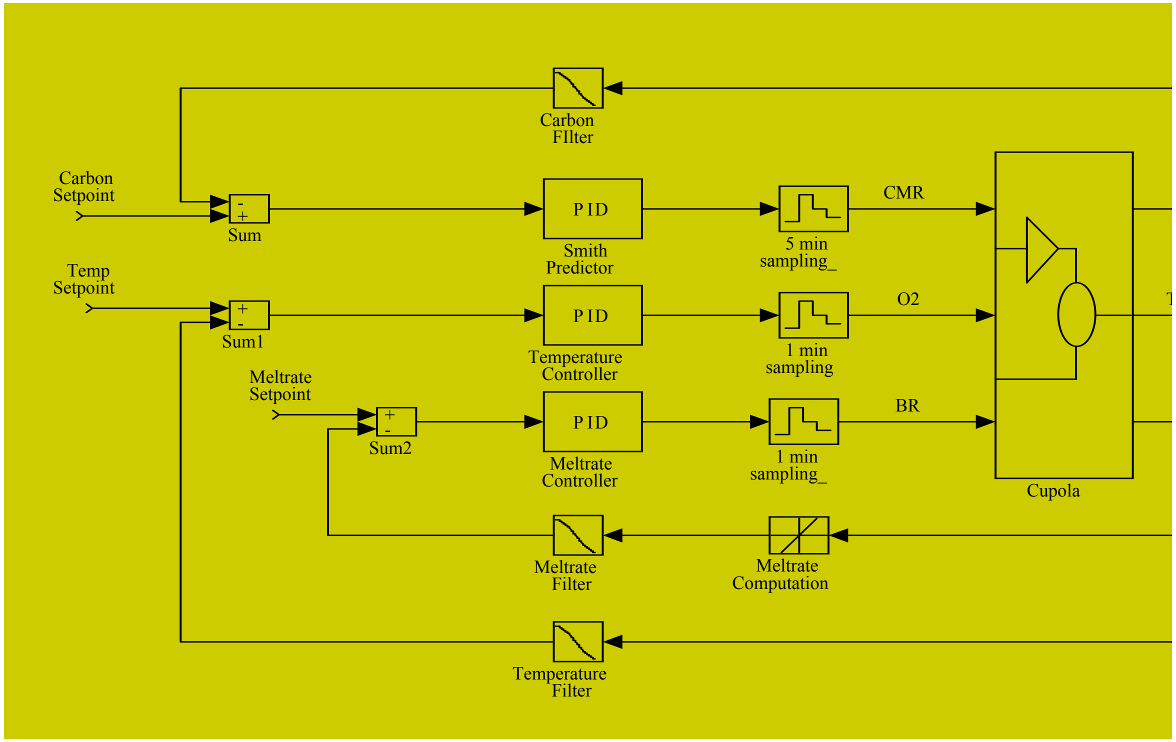
- Cupola furnace is the primary process for melting iron in the US.
- It is used to melt pig iron, scrap metal, cast iron scrap, foundry return scrap, and Ferro-alloys.

Cupola Iron-Melting Furnace ...

- There are approximately 400 cupolas in the United States, which account for 70% of all cast iron production.
- Cupola furnaces are responsible for 1-2% of the total annual national production of green house gas.
- Cupola furnaces are currently manually operated.
- The efficiency and quality of iron produced by a Cupola depends on the experience of the operator.
- Automatic Control of the cupola can lead to increased production efficiency and reduced variability in iron properties.

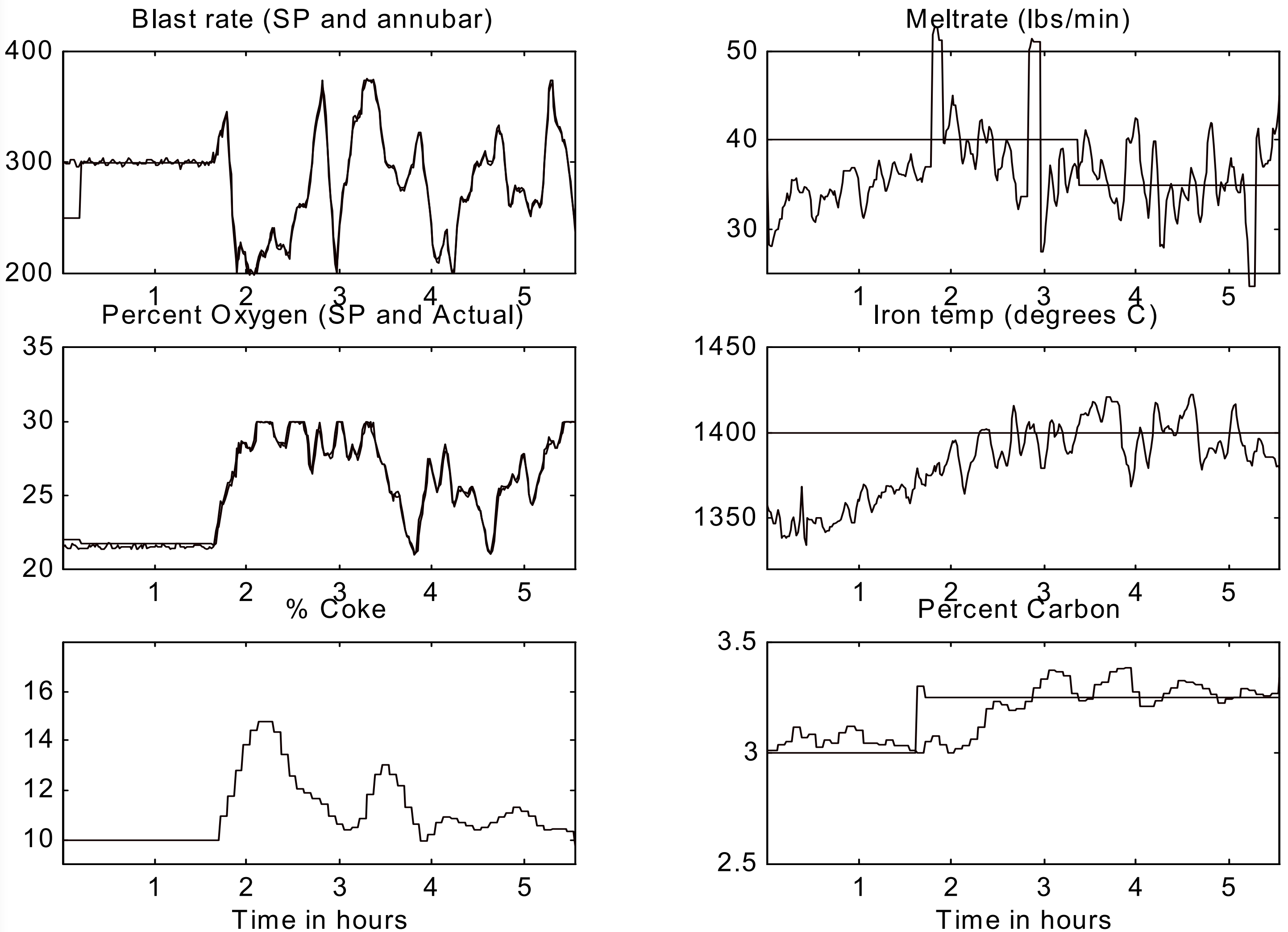
Automatic Cupola Control

- A project for the demonstration of feasibility of automatic control of the cupola furnace was funded by DOE.
- Dynamic model of the cupola was identified through transient tests.
- Experimental testing using an 18” cupola proved the validity of the concept, but highlighted important implementation issues.



Automatic Cupola Control...

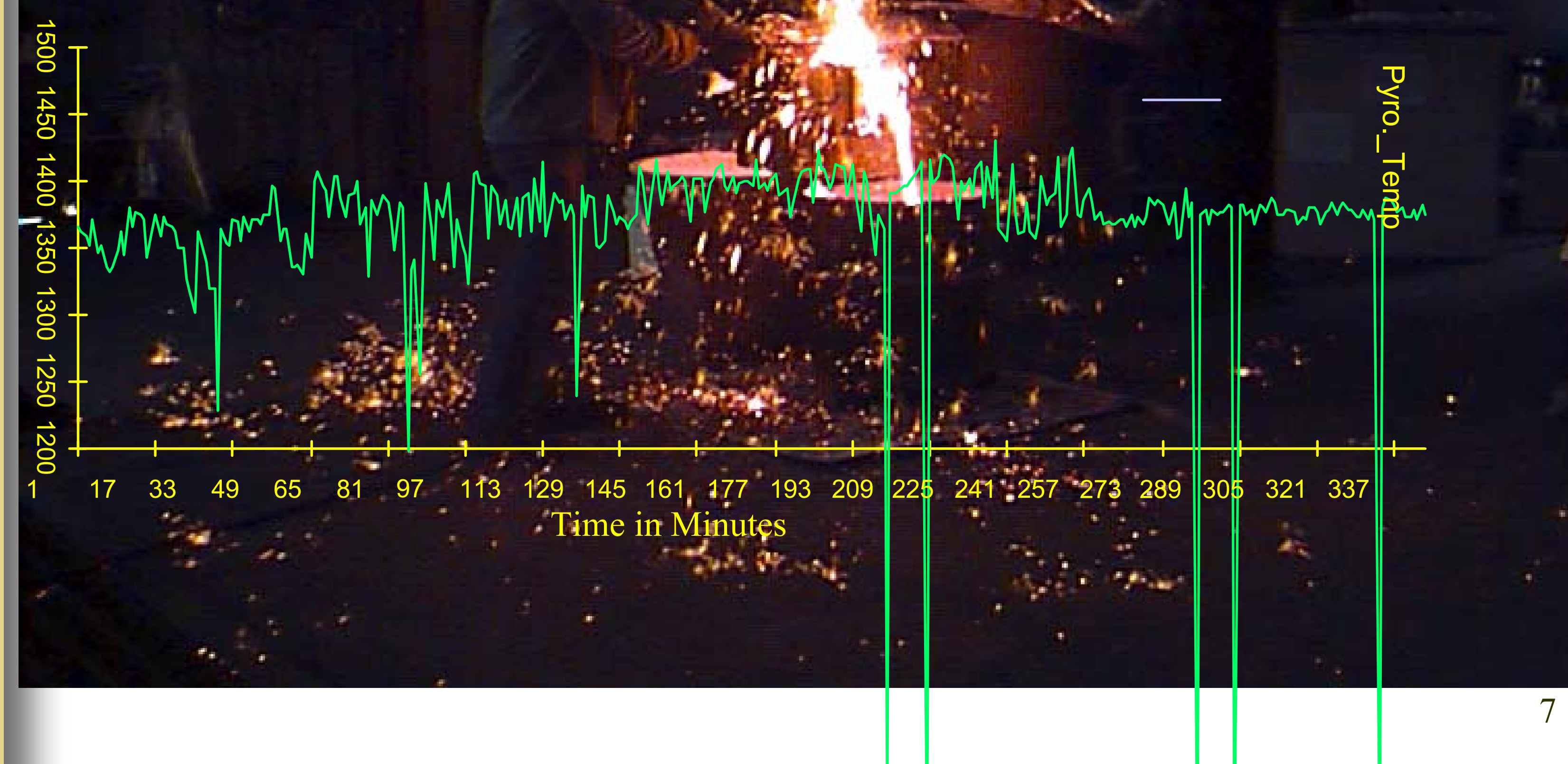
Experimental Testing



Automatic Cupola Control …

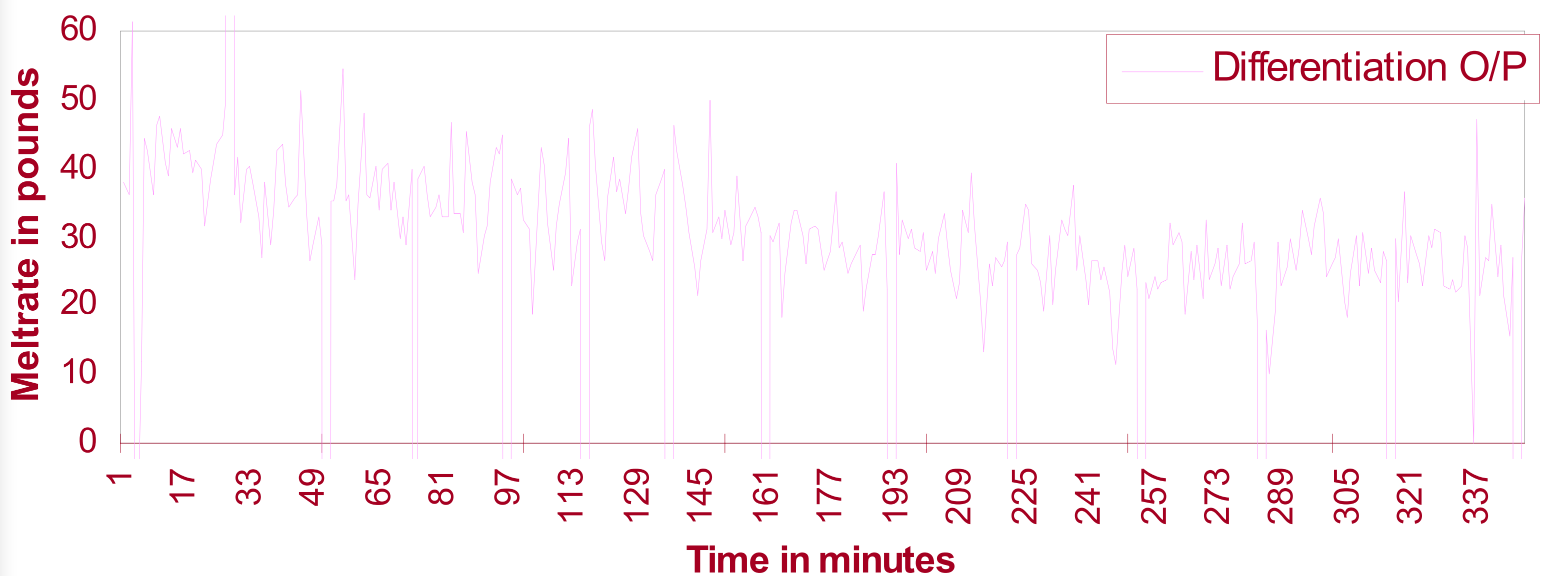
Measurement Problems

- **Key inputs to the controller suffered from noise problems due to harsh environment**
- **Pyrometer**
  - **Focussing**
  - **Interference**



Automatic Cupola Control …
Measurement Problems

- Meltrate
  - Sampling, human interference and calculation problems.



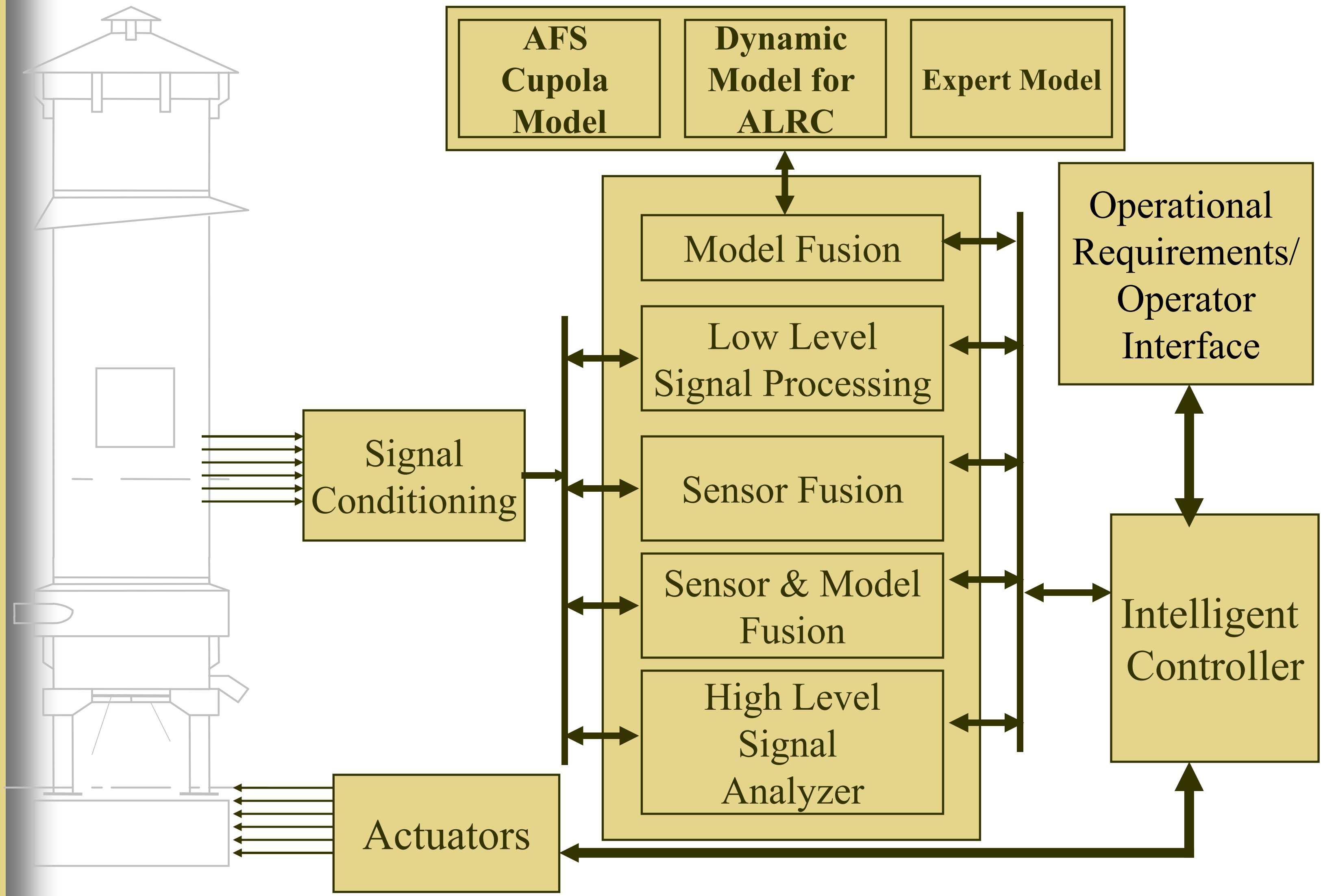
•**Unreliable sensor signals** can lead to erroneous controller decisions. Thus, A integrated sensing and control system is essential for proper cupola automatic control.

Project Scope

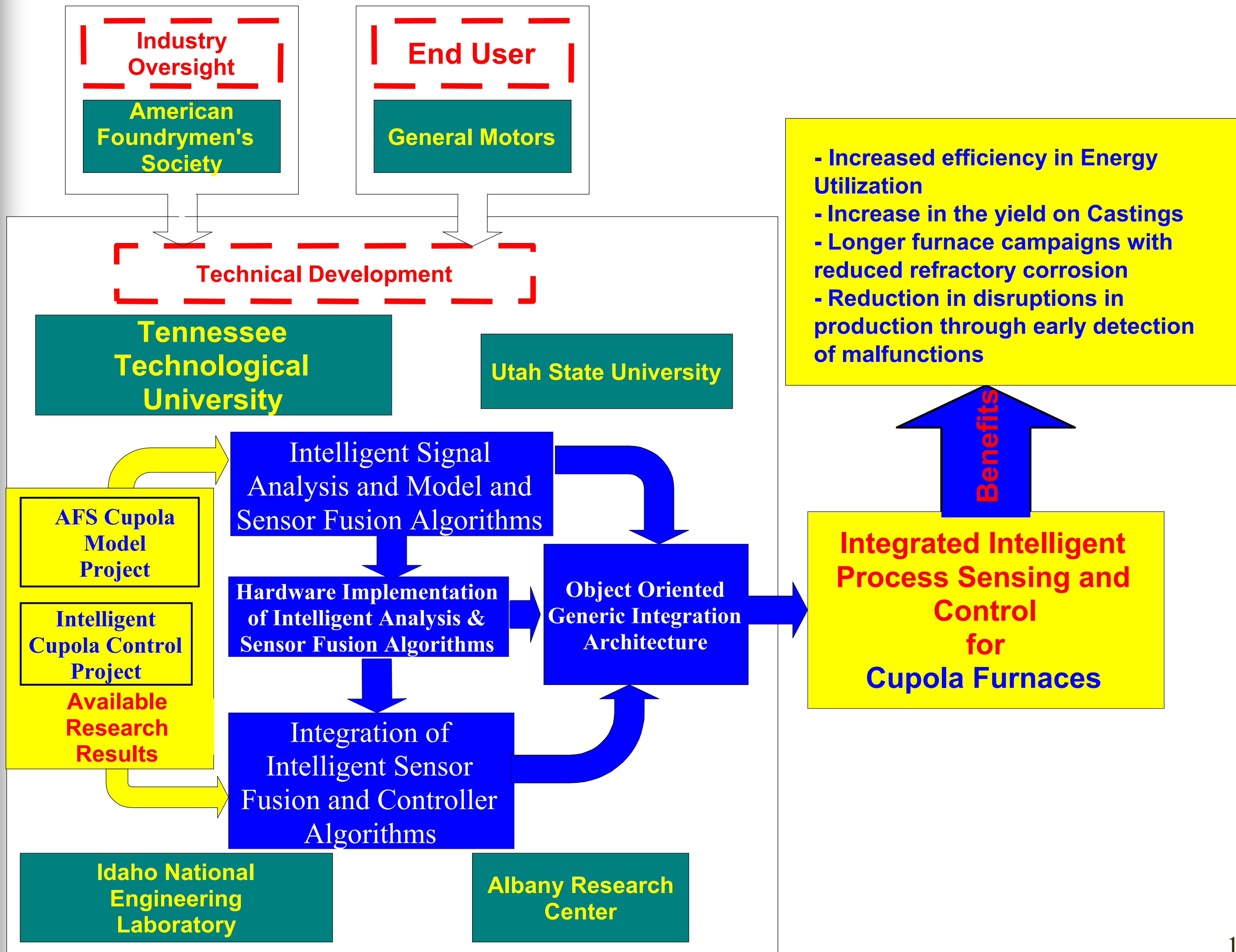
- Development of a *generic architecture* for the ***I***ntegrated, ***I***ntelligent ***I***ndustrial ***P***rocess ***S***ensing and ***C***ontrol system (I^3PSC). The proposed architecture is characterized by:
  - **Intelligent signal processing** capabilities and sensor fusion methodologies,
  - Intelligent algorithms for **hybrid model fusion**,
  - Methodologies for integrating intelligent signal analysis and sensor and model fusion algorithms with **intelligent model-based control** methodologies,
  - Fast **implementation** of the intelligent signal processing and sensor fusion algorithms on dedicated hardware.
- Application of the I^3PSC to the *specific industrial setting* of cupola iron melting furnaces.

Project Scope …

I^{3}PSC Architecture



Project Scope ...



Deliverables

- Generic Architecture for Integrating Sensor Fusion and Control System Components.
- Algorithms for Intelligent Signal Preprocessing, Multi-Modal Sensor Fusion, Model Fusion, Sensor and Model Fusion.
- Algorithms for Integration of Intelligent Sensor Fusion Data into the Controller.
- Dedicated Hardware Implementation of Intelligent Signal Processing and Sensor Fusion Algorithms.
- Prototype Implementation and Testing on the ALRC Cupola.

Demonstration Plans

- Testing of the algorithms using experimental data, and static and dynamic models available from industrial foundries, and the Albany Research Center (ALRC) research cupola.
- Implementation and testing of the I^3PSC system on the 18" research cupola at DOE's ALRC cupola.
- Work with AFS to identify interested foundries where we can apply the I^3PSC technology.

I^3PSC Relation to IOF

- I^3PSC technology is a generic technology that can be applied in any of the IOF.
- More specifically, this type of proposed technology has been identified as a high priority research need in the several IOF roadmaps, such as Metalcasting Industry, Glass Technology, Aluminum, Forest Products, etc.
- Our immediate focus is to improve the operation of cupola furnaces.
- The prospective customers for our technology are ~ 400 cupola foundries in the united states.

Impact of the Technology
Economic Impact

- Increase in efficiency of **energy utilization** by operating cupola closer to optimal operating points and reducing the transition period during changes in production plans.
- Increase in **yield** of castings due to reduction in variability in iron properties and discovery of deviations from the desired production characteristics.
- Stability of the operational conditions will allow longer **campaign length** with the added benefit of reduced **refractory erosion**.
- Reduction in disruptions in production by early **detection of malfunctions**.
- **Reduction in the use of holding furnaces** whose purpose is to level out the variability in the produced iron.

Impact of the Technology
Environmental Impact

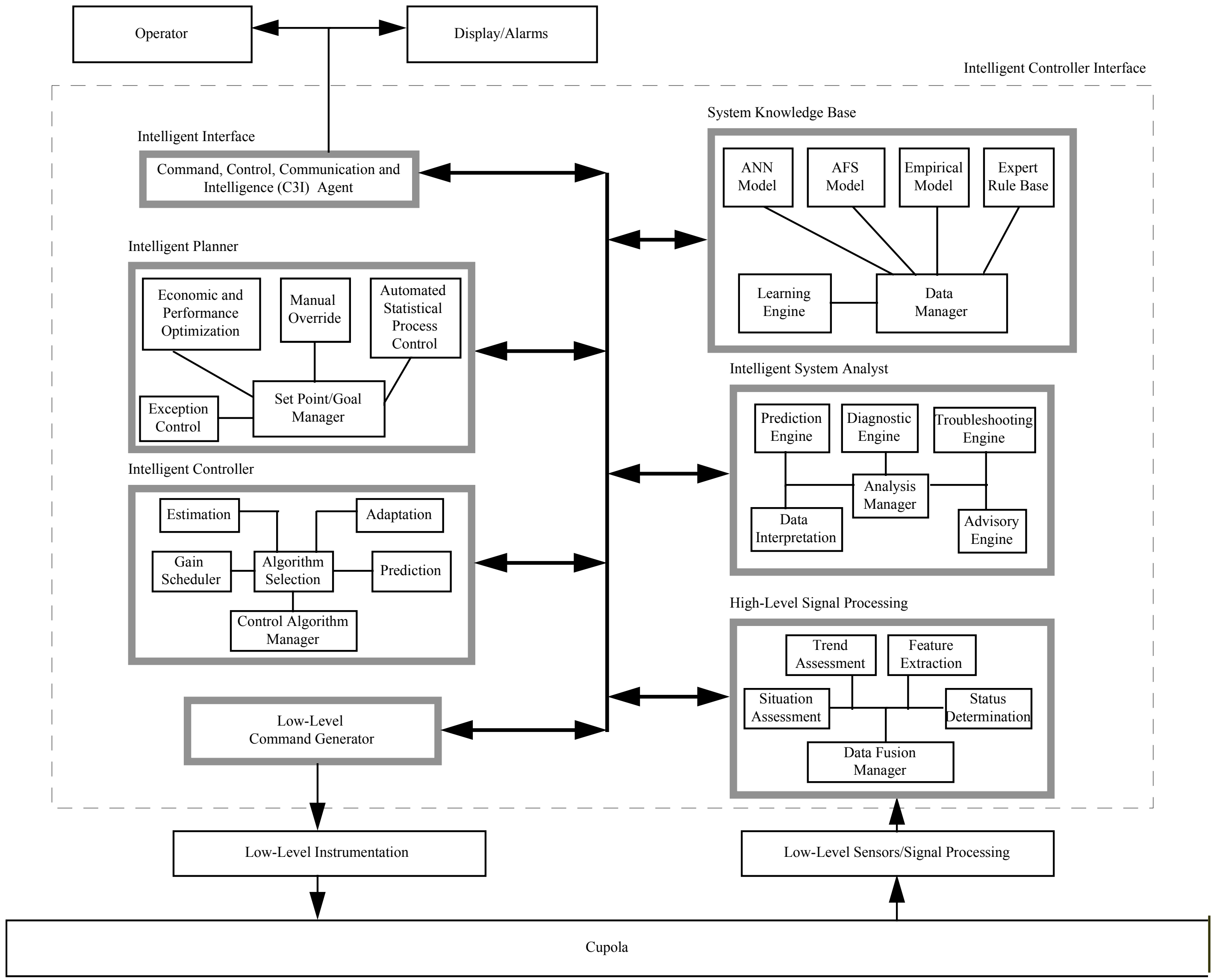
- Cupola furnaces are an appreciable source of green house gas and other gases and particulate.
- Improving cupola efficiency and yield of castings has a direct impact on the environment.
- Cupolas use energy directly from coke, which is more efficient and less harmful to the environment than first producing electricity and then using the electricity in an arc furnace to melt iron.
- Improving cupola operation would reduce the migration towards the use of induction furnaces.

Project Management Activities

- Started forming a project advisory board.
- Developed a detailed Project Management Plan.
- Placed subcontracts.
- Identified students and organized teams.
- Started communicating with foundries to identify some that might be interested in testing the developed technology on their cupolas (US Pipe, AL, Iron Research Institute).
- Public Relations & Technology Marketing (OIT Expo., AFS Congress Presentation, I^3PSC Web Page, American Control Conf., Southeastern Symposium on Systems and Theory).
- Established Mechanisms for communication between teams (ftp site, Webboard, …).

Technical Activities

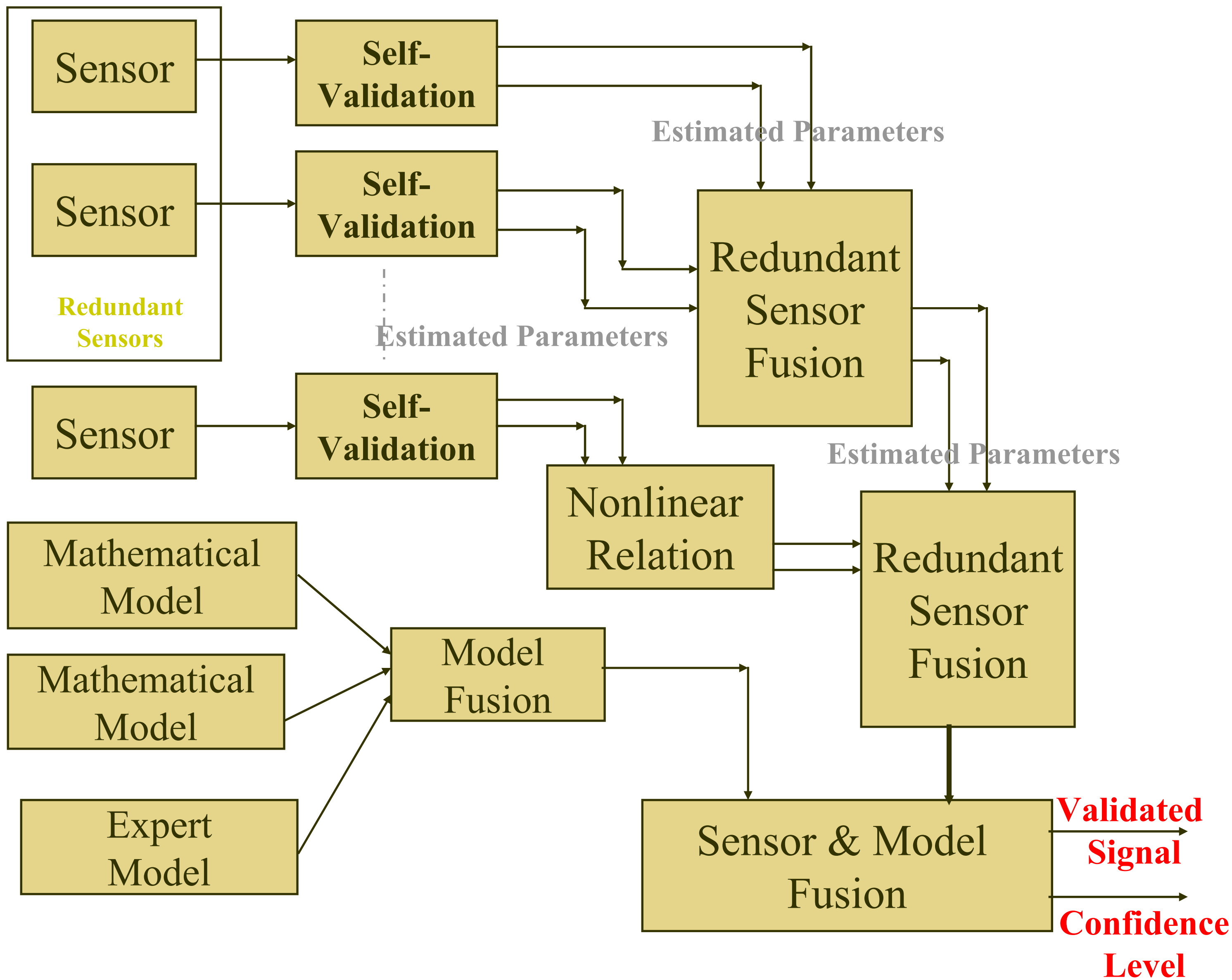
I^{3}PSC Architecture



Technical Activities
Intelligent Signal Analysis
Current Status

- Data set reduction
  - ALRC data has been acquired and reduced to meaningful parameters
- Feature extraction
  - Developed and implemented preliminary algorithms for feature extraction using fuzzy logic
- Self-validation
  - Paper search on methodology complete
  - Promising techniques have been identified
  - Development of pre-processing and fuzzy logic algorithms has begun
- Sensor fusion
  - Paper search has started
  - Promising techniques have been identified

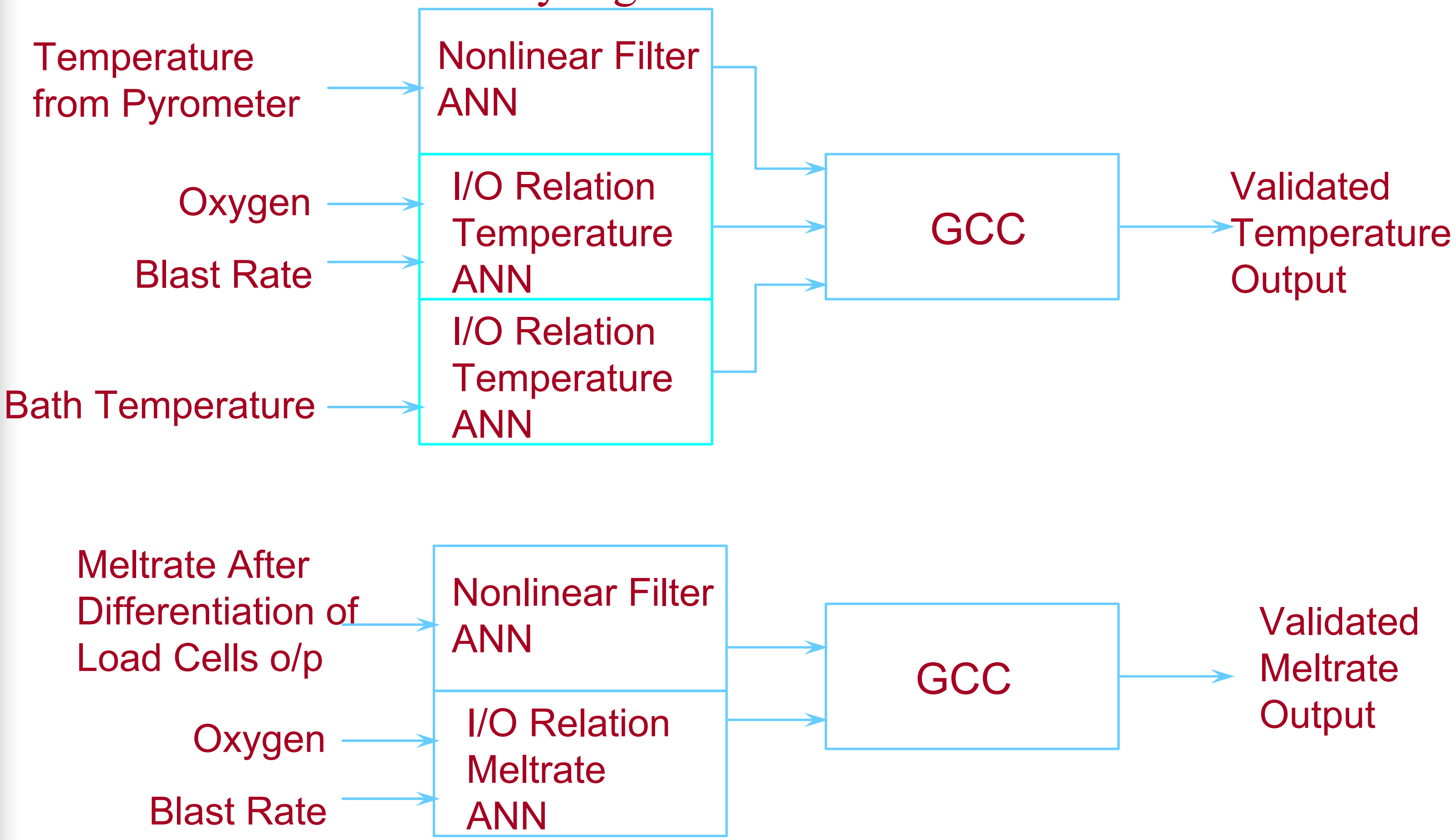
Schematic for Fusion Sub-Systems



Technical Activities

Intelligent Signal Analysis...

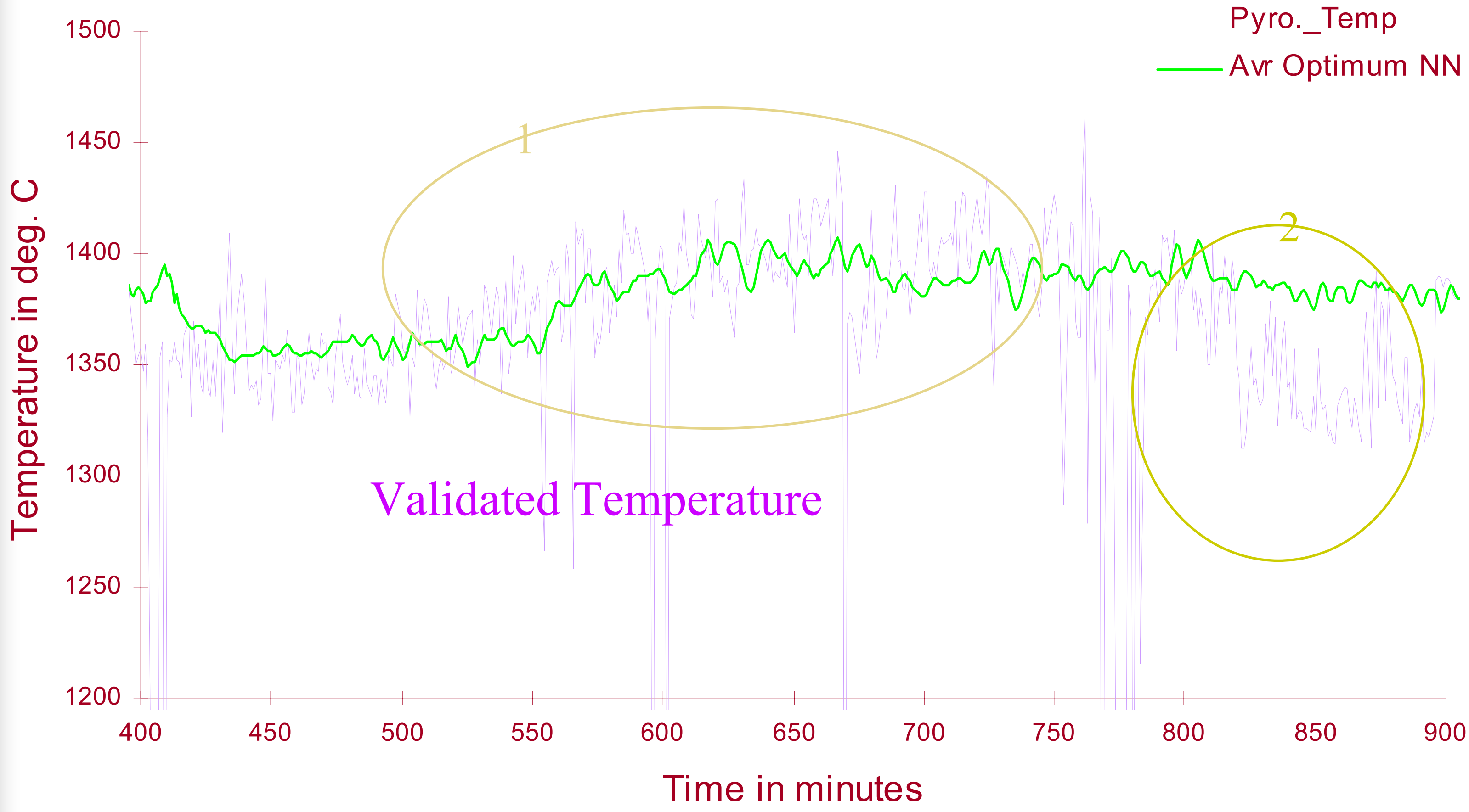
Preliminary Signal Validation Schematic



Technical Activities

Intelligent Signal Analysis...

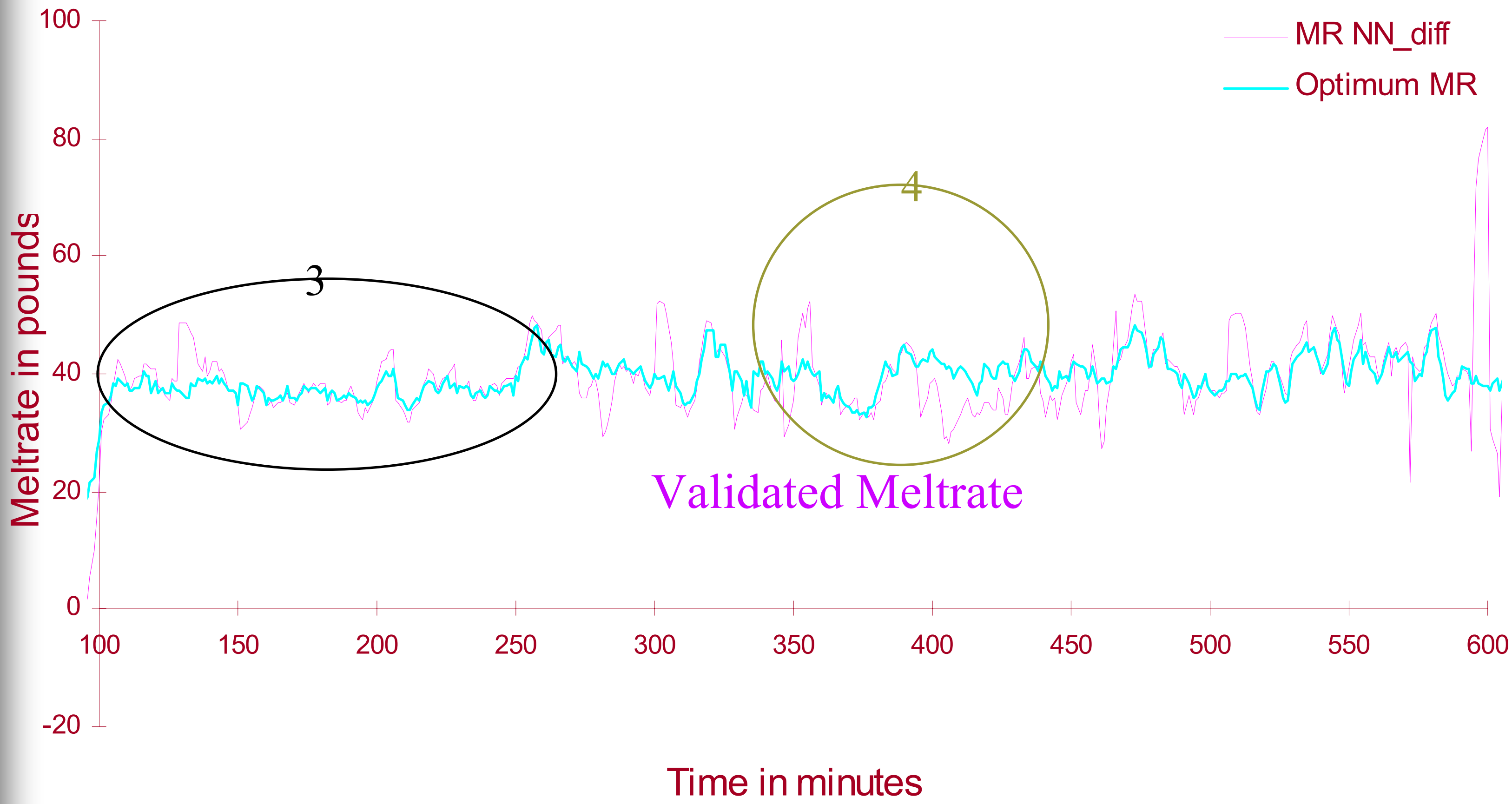
Preliminary Signal Validation Schematic



Technical Activities

Intelligent Signal Analysis...

Preliminary Signal Validation Schematic



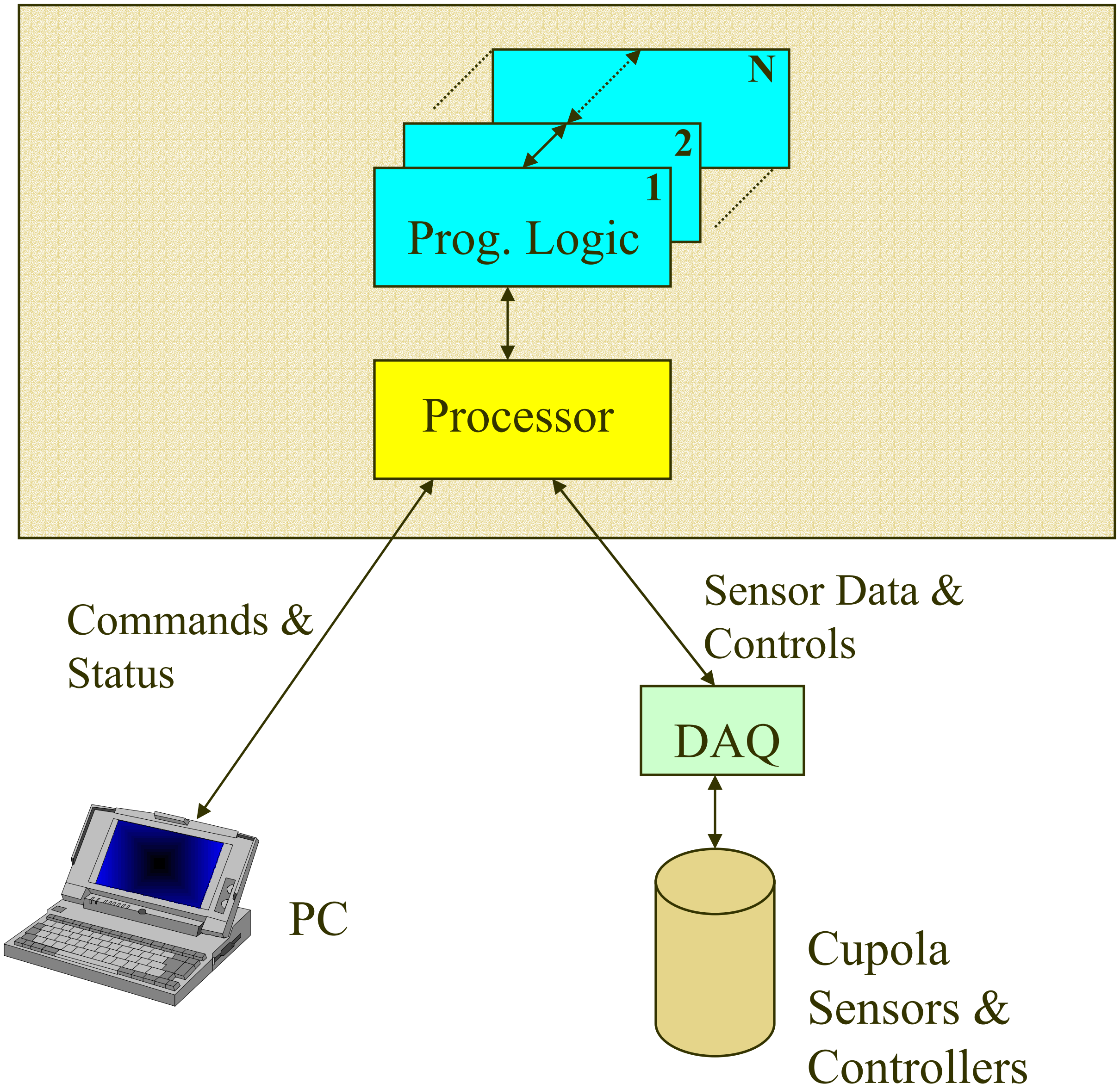
Technical Activities
Intelligent Signal Analysis...
Short Term Goals

- Data Set Reduction
  - Develop an approach to automating this process.
  - Begin investigation of data set compensation methods.
  - Develop Monte Carlo and investigate blind deconvolution compensation methods.
- Self-Validation
  - Complete preliminary set algorithms.
  - Deliver preliminary set of algorithms to hardware group.
  - Fine tune algorithms to produce final set.
- Redundant Sensor Fusion
  - Complete paper search for redundant sensor fusion.
  - Develop algorithms which implement the promising techniques for redundant sensor fusion.
  - Deliver preliminary set of algorithms to hardware group.
- Multi-Model Fusion
  - Begin literature search.

Technical Activities
Hardware Implementation
Current Status

- Studied overall signal processing requirements
- Researched hardware implementation methods
  - Fuzzy Logic
  - Artificial Neural Networks
- Developed system architecture
- Selected suitable prototype boards
  - Processor
  - Programmable Logic
  - Data Acquisition

Hardware Implementation



Technical Activities
Hardware Implementation
Future Goals

- Determine required computational methods
- Allocate computations to appropriate programmable hardware and software implementations
- Evaluate effects of limited precision, fixed point arithmetic
- Assemble hardware system
- Design and test
  - Interface between processor and prog. logic
  - Interfaces to PC and DAQ
  - software and hardware algorithms for implementing intelligent signal analysis algorithms