Integrated Intelligent Industrial Process Sensing and Control Demonstrated on Cupola Furnaces

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Collaborations

- Tennessee Technological University
- Utah State University
- Idaho National Engineering Laboratory
- American Foundry Society
- General Motors
- Albany Research Center
- US Pipe

Overview

- Introduction
- Objectives
- Object Oriented Framework
- Multi-Modal Sensor Fusion
- Intelligent Controller
- Generalization and User Interface
- Results
- Conclusions

Cupola Furnace

Charging System

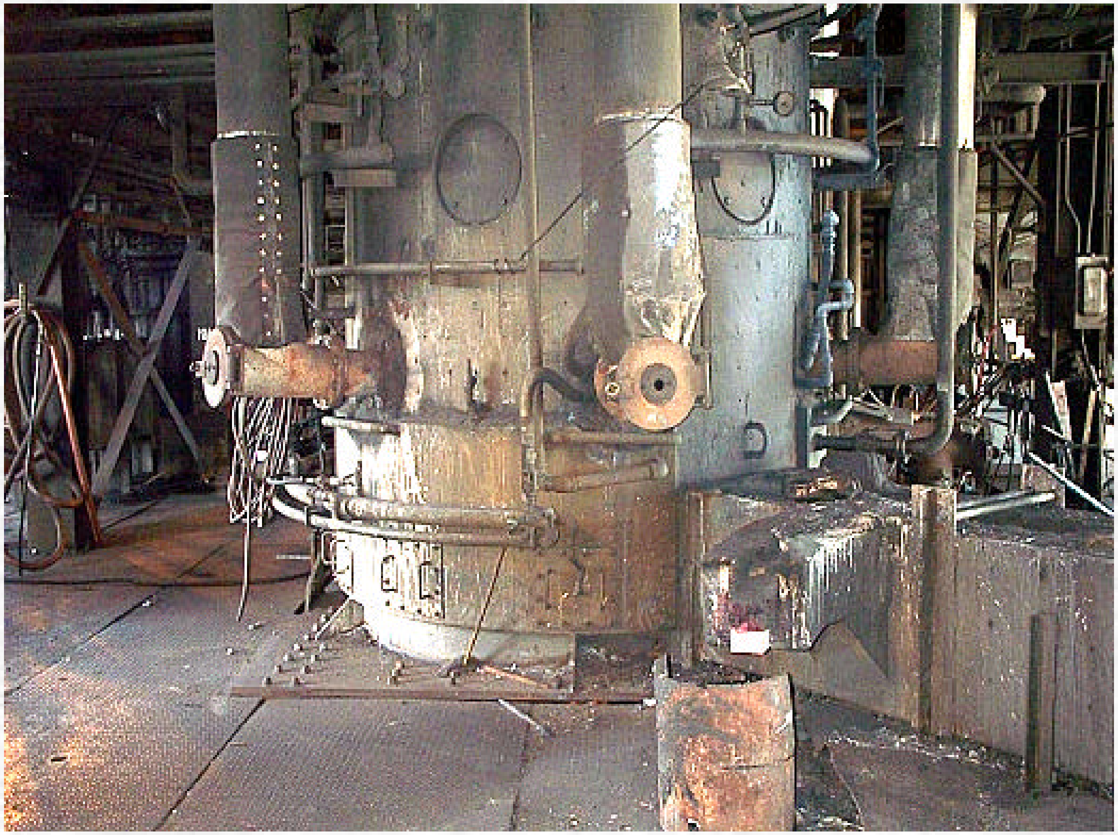
View from Tuyere

Control Room

Charging Materials

Cupola Furnace

Tap hole

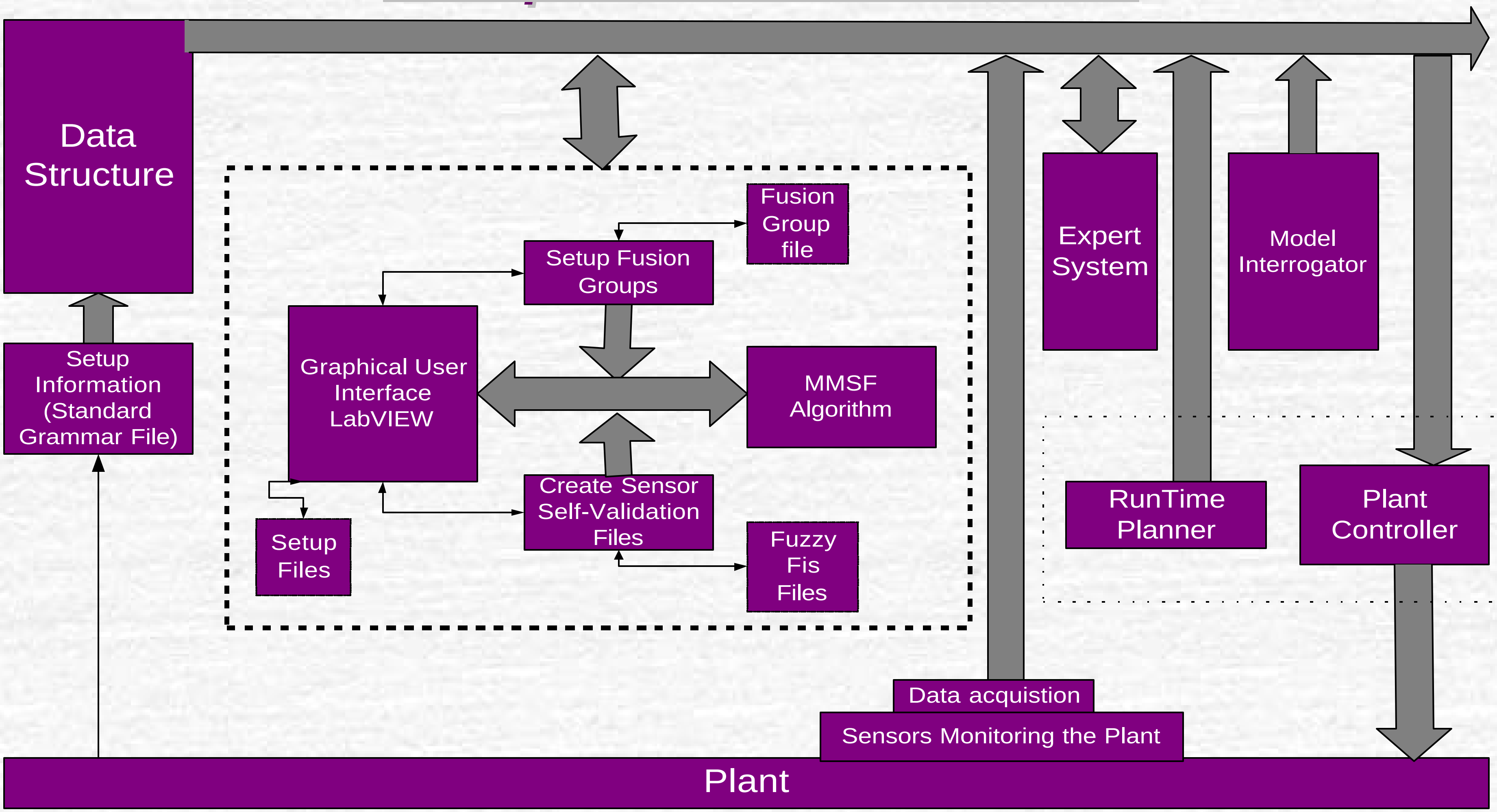


Cupola Furnace Shaft

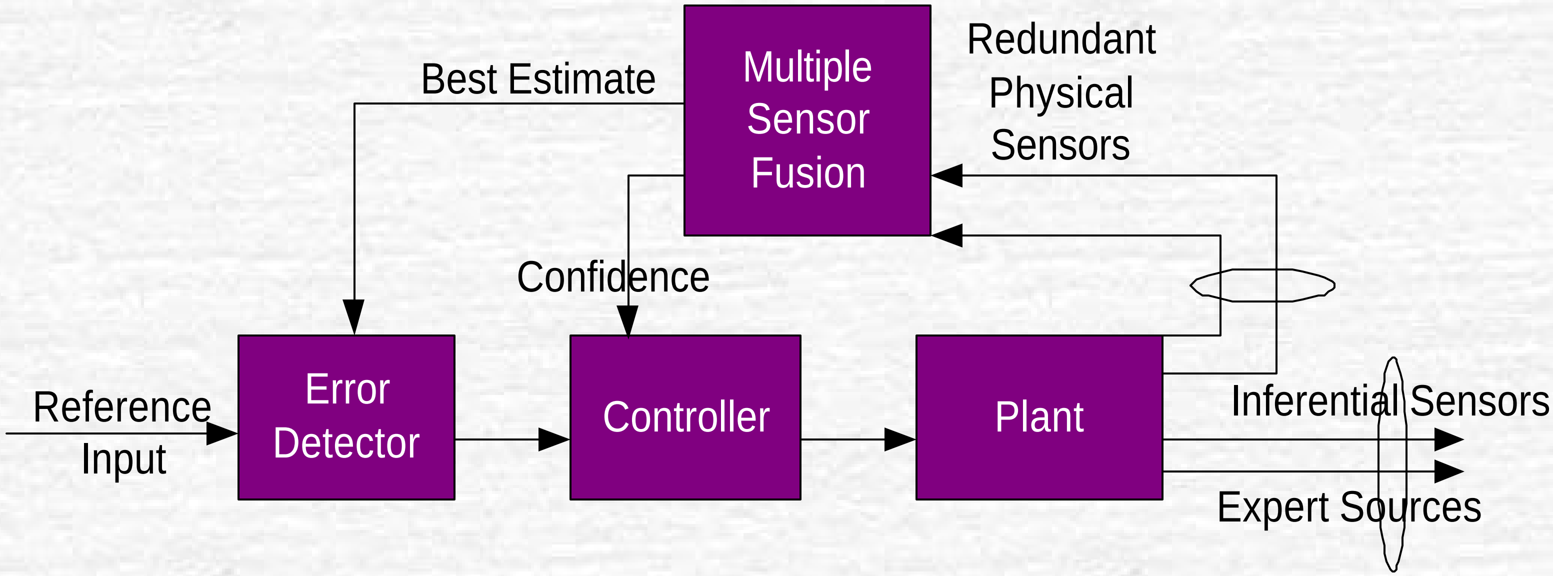
Objectives

- Unified Framework for Integration of
  - •Multi-Modal sensor Fusion,
  - •Intelligent Controllers, and
  - •Expert System and Offline Data Analysis Module
- Generalized, Object Oriented Open System Architecture
- GUI for System Setup and Operation
- Proof of Concept of HW Implementation using FPGA
- Demo on Cupola Furnaces

Unified Framework

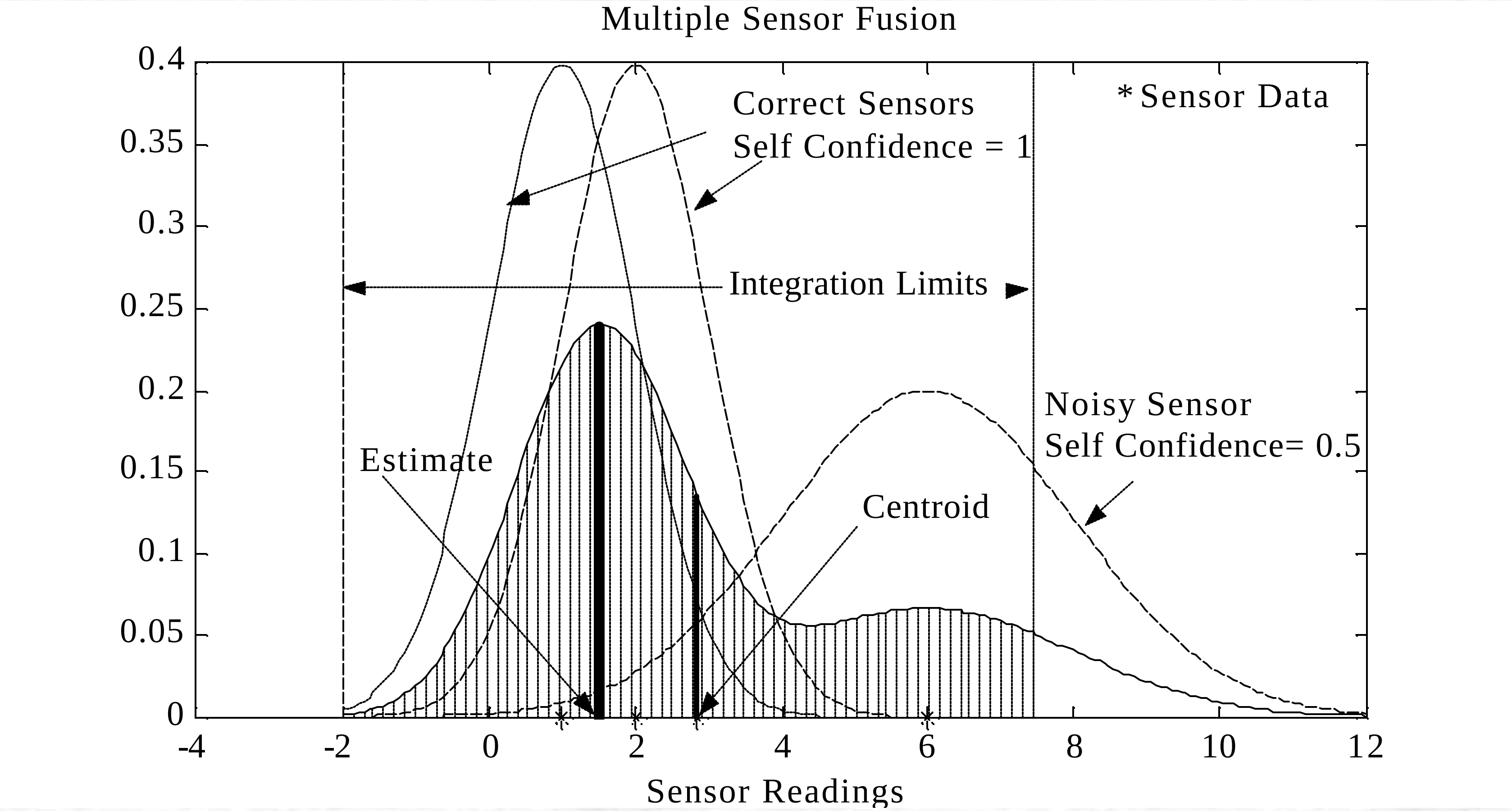


MMSF Fusion: Review MSF

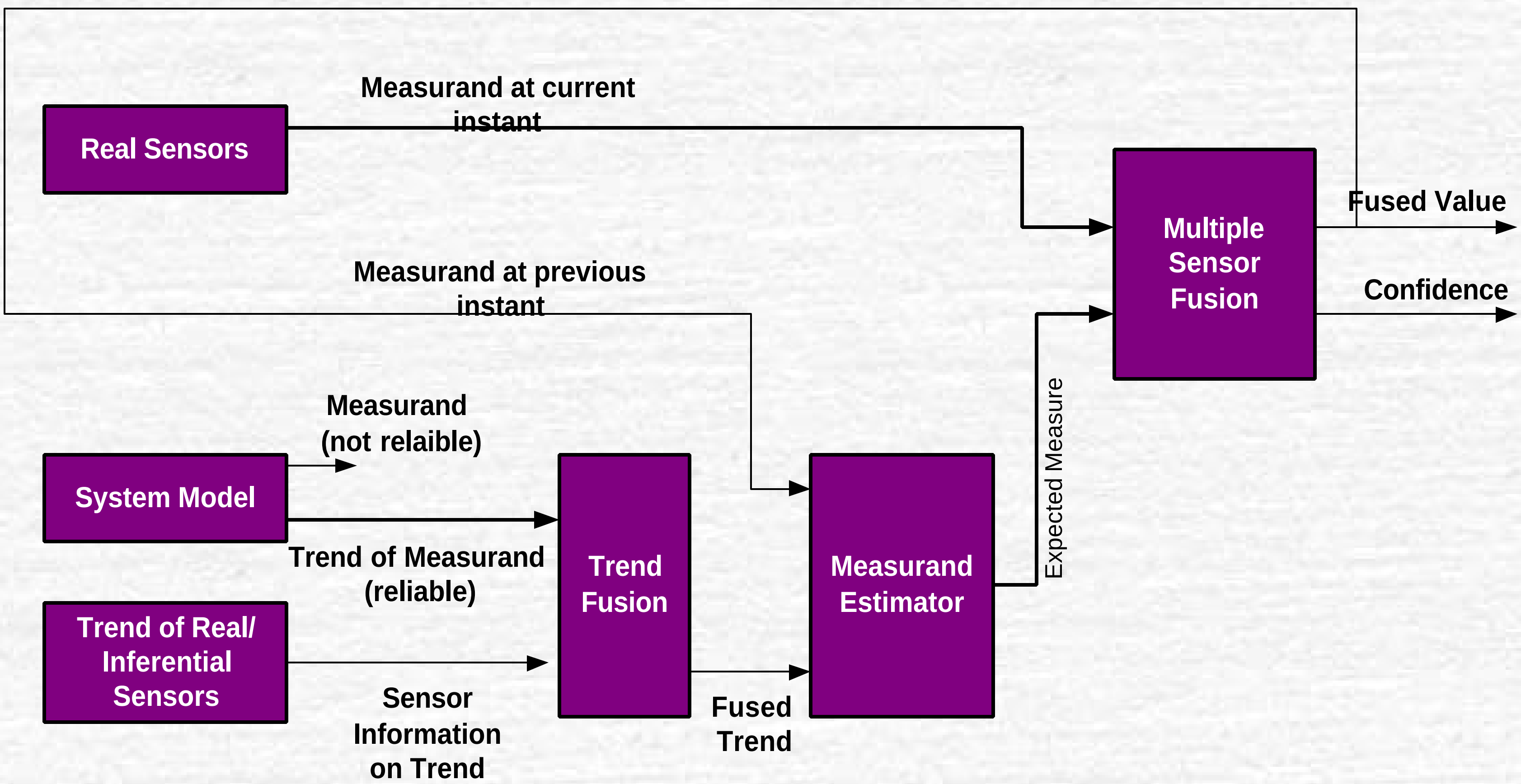


Trend Information Not Used

MMSF Fusion: Review MSF



MMSF Fusion



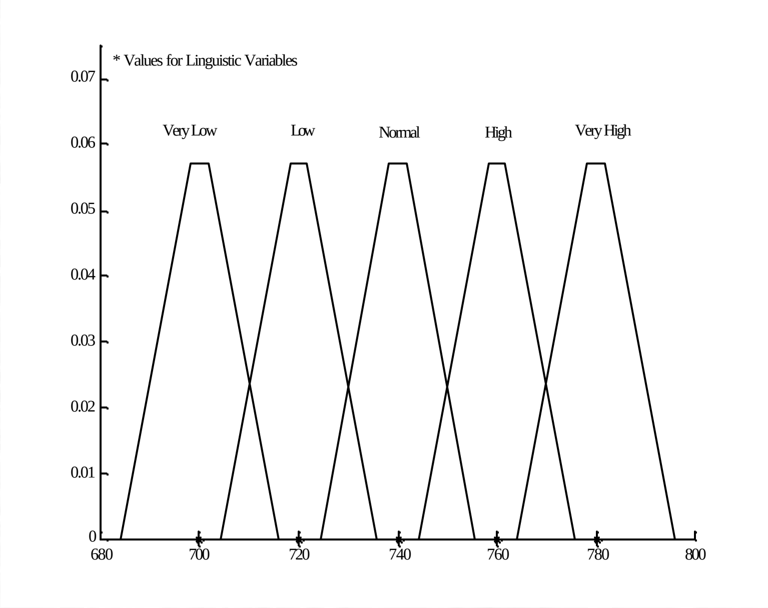
Real Sensors
Measurand at current instant
Multiple Sensor Fusion
Fused Value
Confidence
Measurand at previous instant
Measurand (not relaible)
System Model
Trend of Measurand (reliable)
Trend of Real/ Inferential Sensors
Sensor Information on Trend
Trend Fusion
Fused Trend
Measurand Estimator
Expected Measure

MMSF::Inferential Sensors

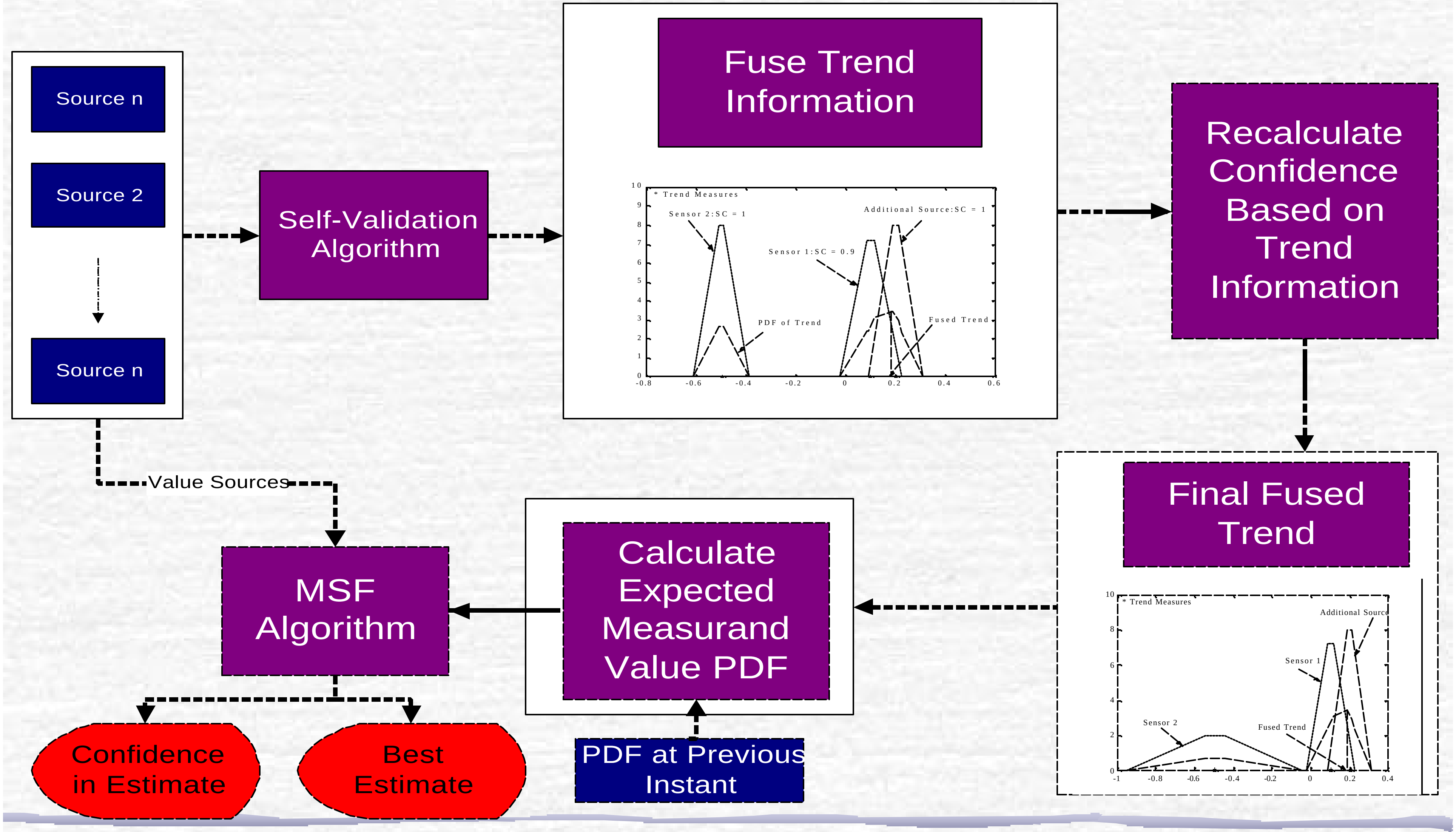
- Provides Trend/Value Measurand information.
- Melt Rate Inferential (Virtual) Sensor
  - ANN Trained using Real Plant Data
  - Inputs: Blast Rate and Oxygen Enrichment
- Iron Temperature Inferential (Virtual) Sensor
  - ANN Trained using Real Plant Data
  - Inputs: Blast Rate, Oxygen Enrichment, and Bath Temperature
- Incorporated directly into MMSF algorithm.

MMSF::Expert Systems

- Provide linguistic information on status of operation.
- Status of operation of trend/value is classified as:
  - Sharply Decreasing/Very Low,
  - Decreasing/Low,
  - Steady/Normal,
  - Increasing/High, and
  - Sharply Decreasing/Very High.
- Convert linguistic information to PDF
  Based on confidence in Source



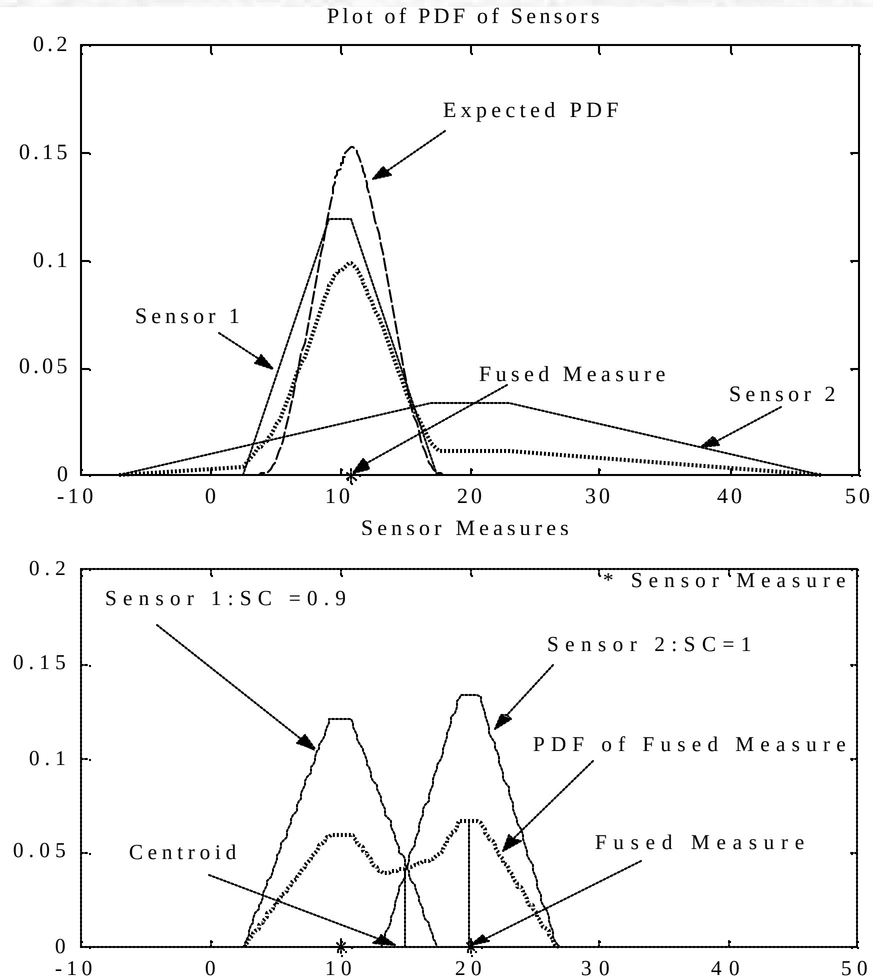
MMSF Algorithm Summary



MMSF::Example...

- Final Result -MMSF

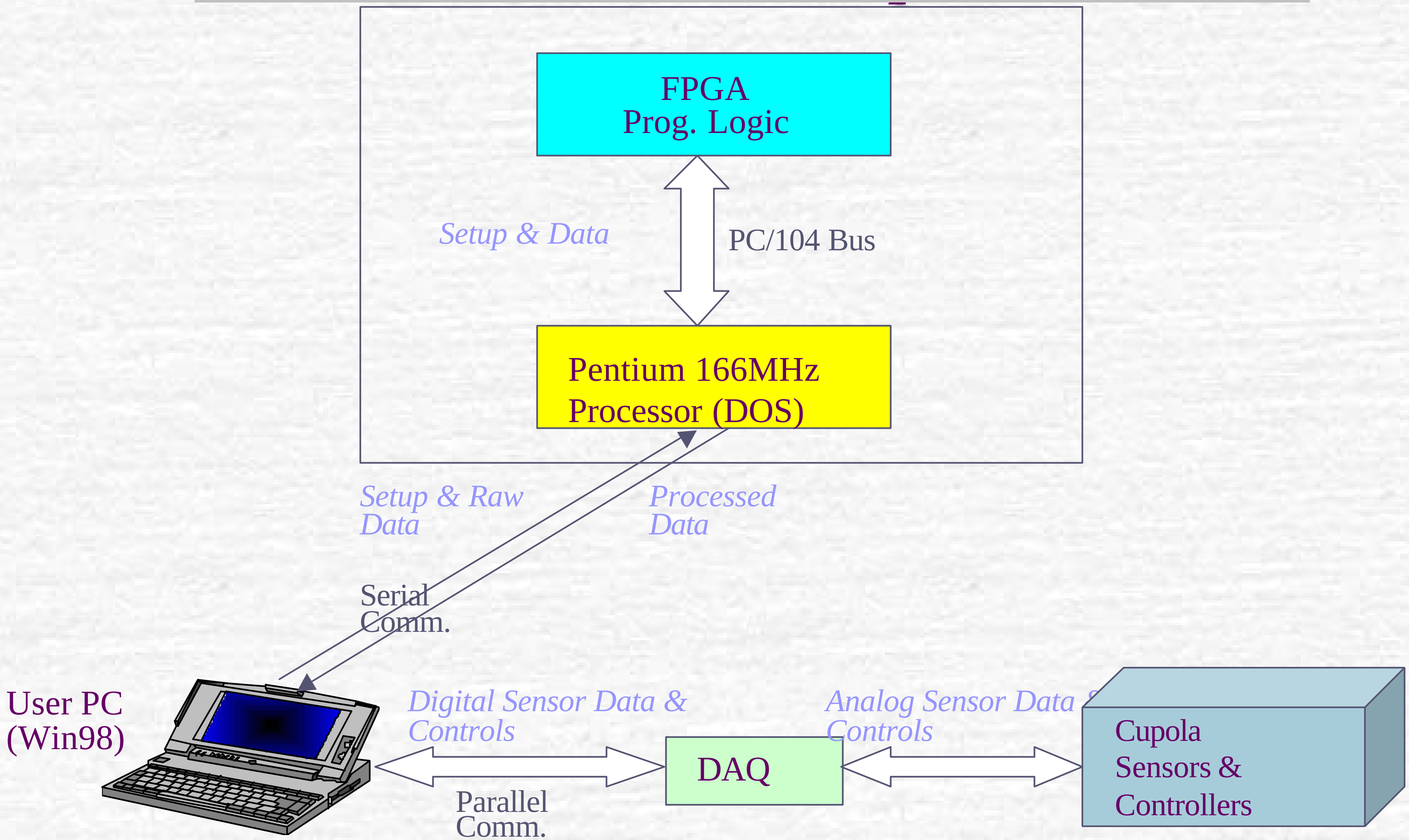
- Comparison with MSF algorithm



MMSF::Hardware Implementation

- Completed Design and Test
  - Allocation of computations between programmable hardware and Processor software implementations
  - Programmable hardware for Self-Validation signal processing algorithm
  - Hardware/Software interface between Processor board and FPGA board
- In-progress Design and Test
  - FPGA programmable hardware for Multi-Sensor Fusion signal processing algorithm
  - Communication software between User PC and Processor

MMSF::Hardware Implementation



Intelligent Controller

Design Objectives

- Account for non-linearities in the process, and have strategies for handling them.
- Handle noisy measurements appropriately by making use of sensor fusion algorithms.
- Allow operators to define operational parameters, schedule changes, and create heat profiles.

Design Challenges

- Charge Materials have long time delay that makes feedback control very difficult.
- Many aspects of Cupola operation are not modeled, so model based control is difficult.
- Information relevant to control will come from many sources, such as actual sensors, sensor fusion, virtual sensors, AFS model, predictions, and even operators.

Intelligent Controller:: Design Approach

Control is divided into Two Parts

Planner

- User Interface where the operator plans a cupola run. Control variables are declared, setpoints are defined, and transitions are scheduled.
- Cupola Inputs are calculated based on defined setpoint schedule.
- Contingency plans can be developed in case of unplanned events (bridging, production line going down, etc.).

Intelligent Controller

Does not require model to perform control.

- Can incorporate multiple data types and sources to make control decisions.
- Configurable to achieve control of nonlinear and noisy processes.

Intelligent Controller::Creating Heat Plans

Plans are created in segments

- Start Up
- Steady Burn
- Transition
- Shutdown
- others?

The length and the operational points for each segment are defined, as are the overall start and stop time.

Inputs are currently determined from the defined setpoints through an inverse model. Development continues in this area in order to provide accurate as possible values for the cupola inputs.

Intelligent Controller::Creating Heat Plans…

Data Structure

Heat Plan

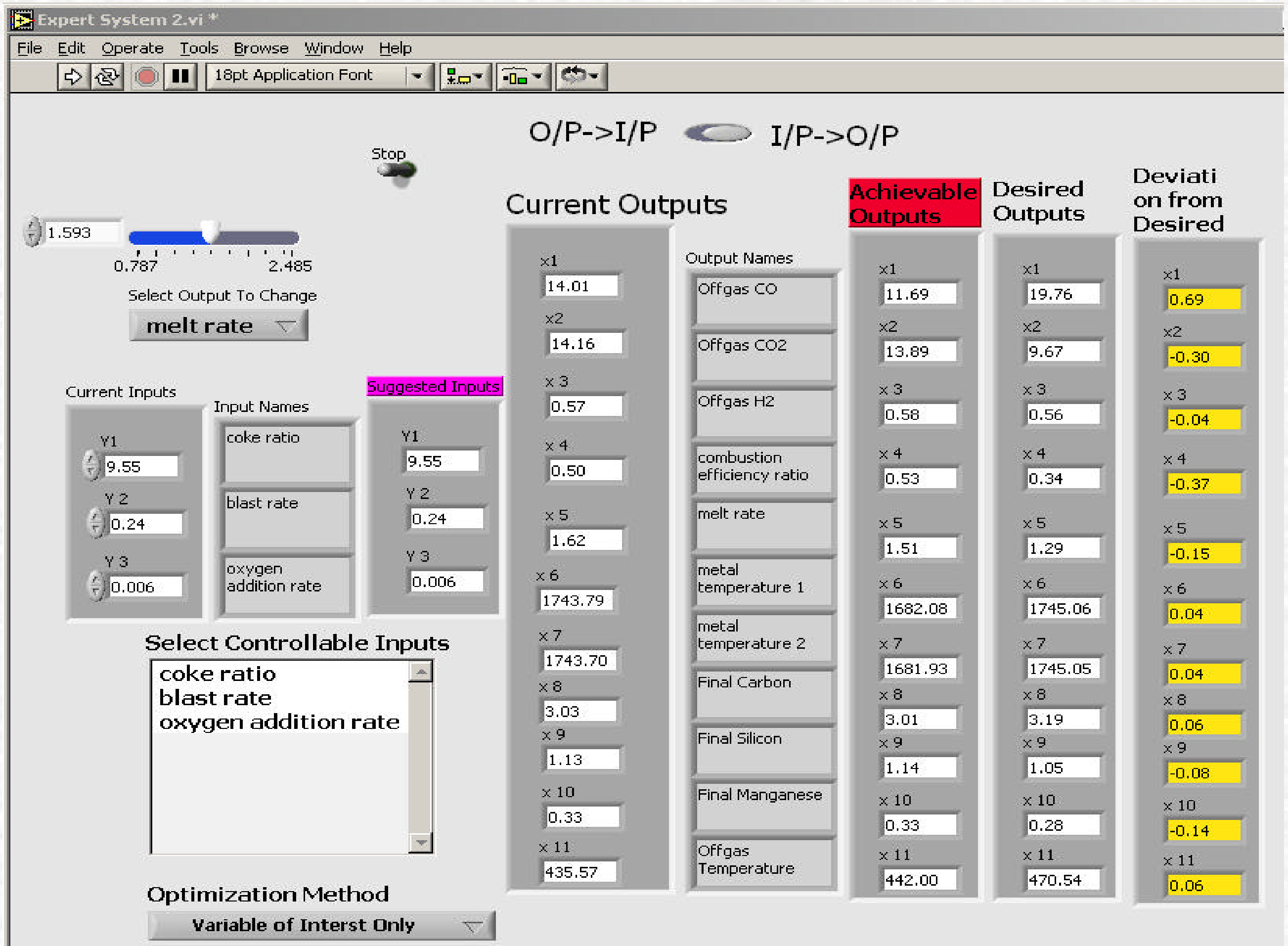
- Time Series array of Setpoints.
- Time Series array of Operating State information (transition, steady burn, etc.).
- Time Series array of calculated Cupola Inputs.
- Each point in the Time Series array corresponds to the information for one minute.

Controller

On start up, shut-down, and transitions, the cupola is operated open-loop using the Cupola inputs provided by the Planner & Expert System.

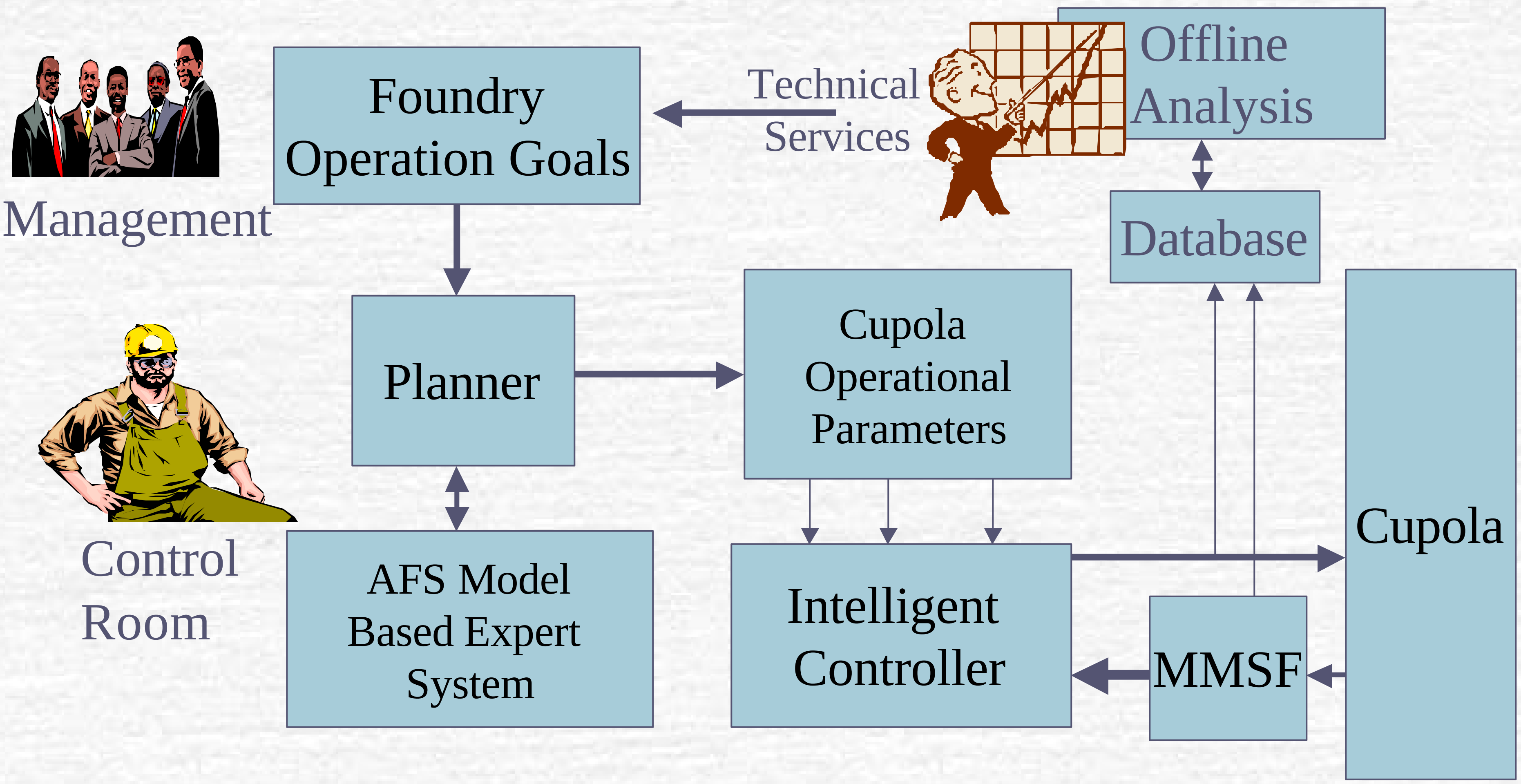
- During Steady Burn segments, feedback control is maintained using Fuzzy Controllers.

Preliminary AFS-Model-Based Expert System

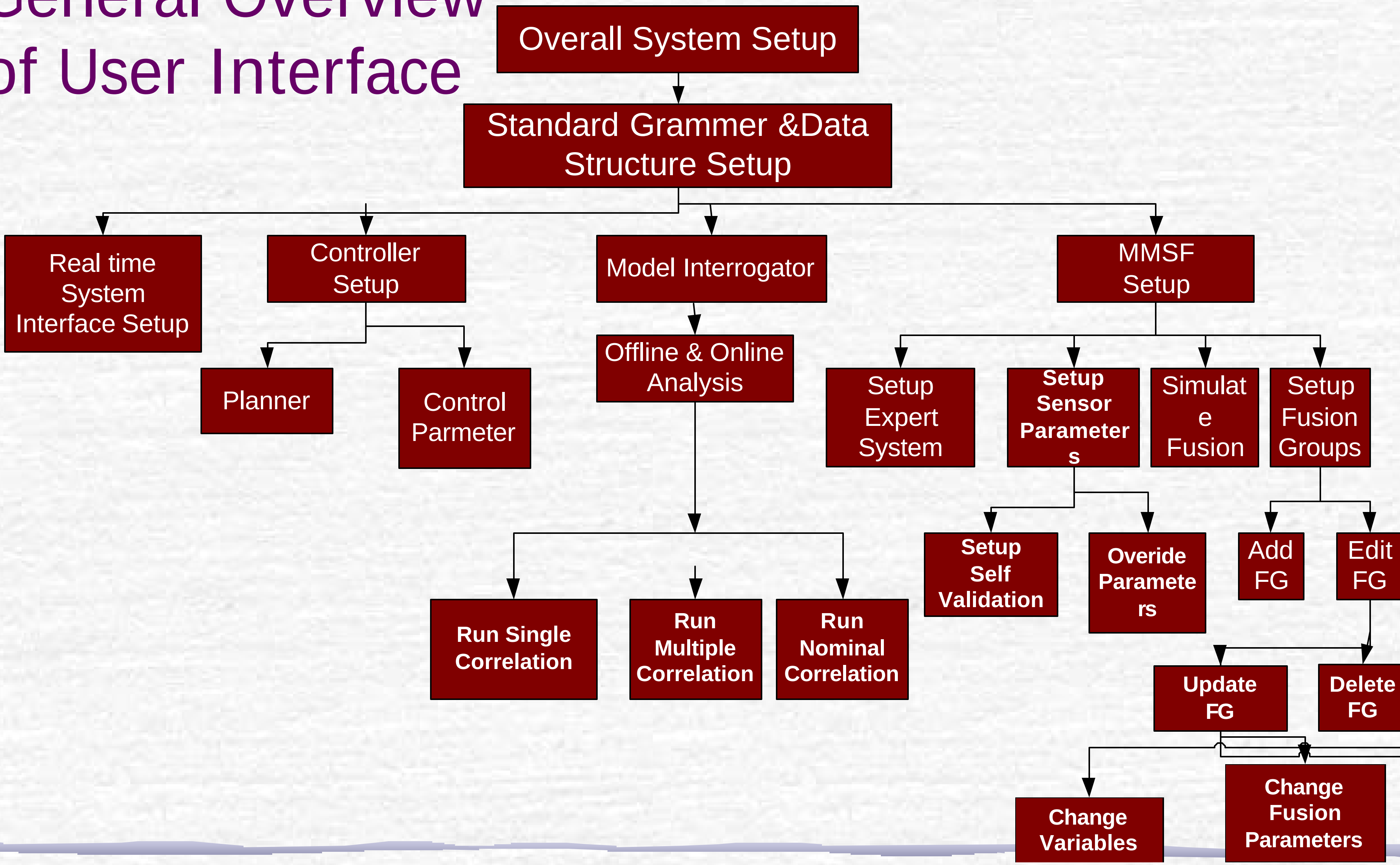


- Based on Model Interrogator for AFS Cupola Model
- Suggests Input Changes for Major Operational Transitions in Cupola
- Allows for Optimization and Constrained Operation

Summary of Controller Architecture



General Overview of User Interface

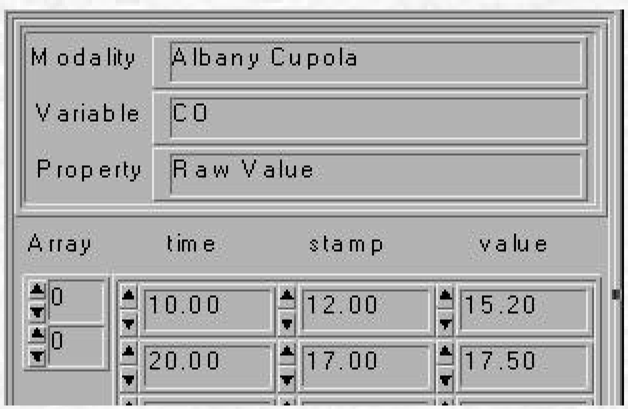


User Interface::Standard Grammar

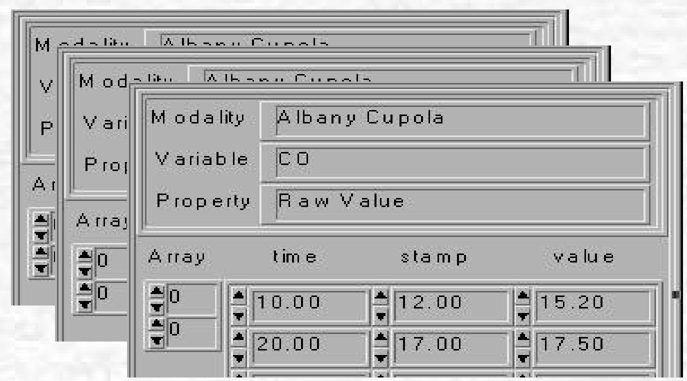
- Backbone of the Datastructure and User Interface.
- ASCII text file.
- Lists all Modalities and Variables (Sensors).
- Different Sensor Names in Different Modalities
- Structure governed by strict rules.

User Interface::Data Structure

- Built on Standard Grammar
- 4-Dimensional array
- Data storage Unit is a "*Node*"
- Allows for Access by Multiple Objects
- Allows for Distributed Computing



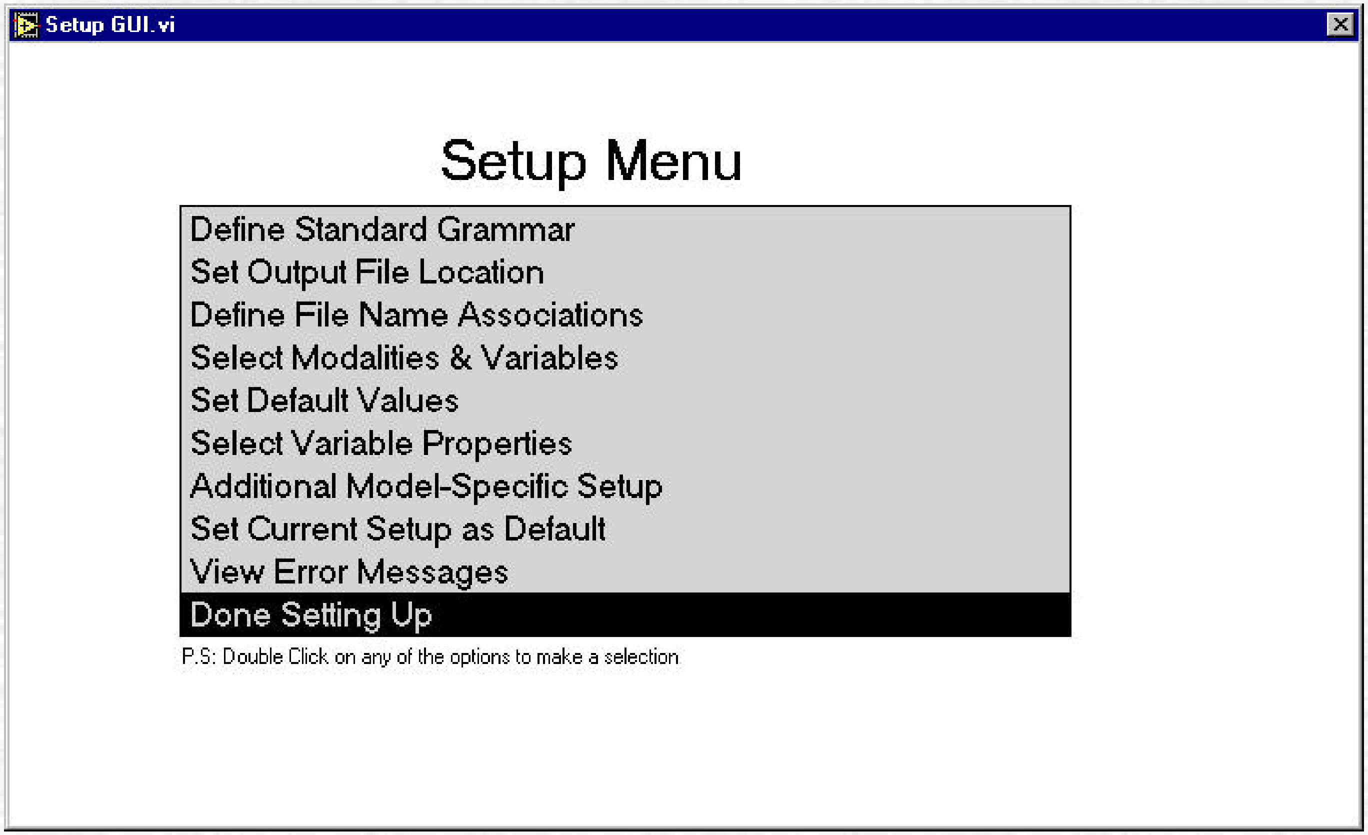
Structure of A Single Node



Data Structure Made-up of Nodes

User Interface::System Setup

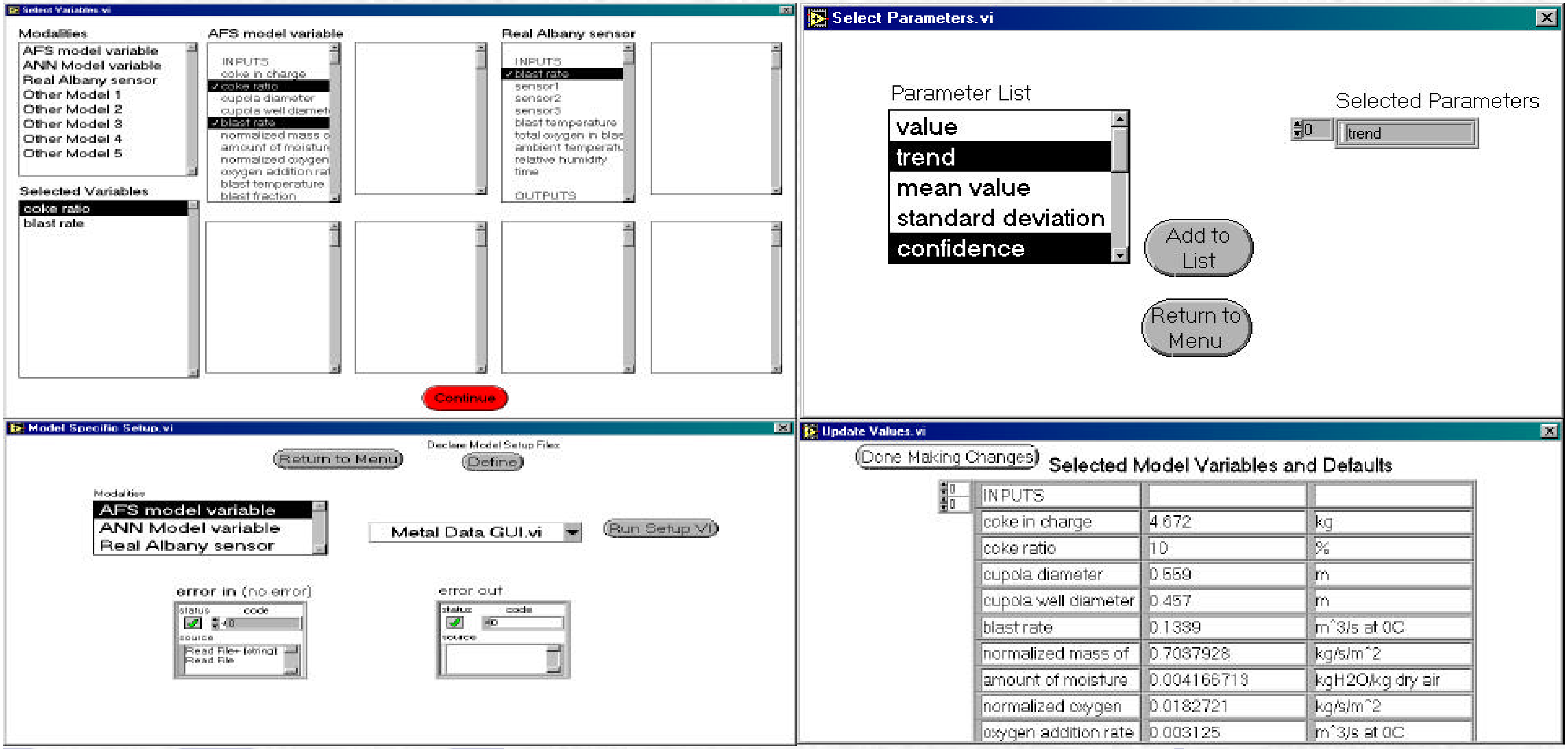
Main Menu



Main Menu for setting up or Modifying overall System Structure

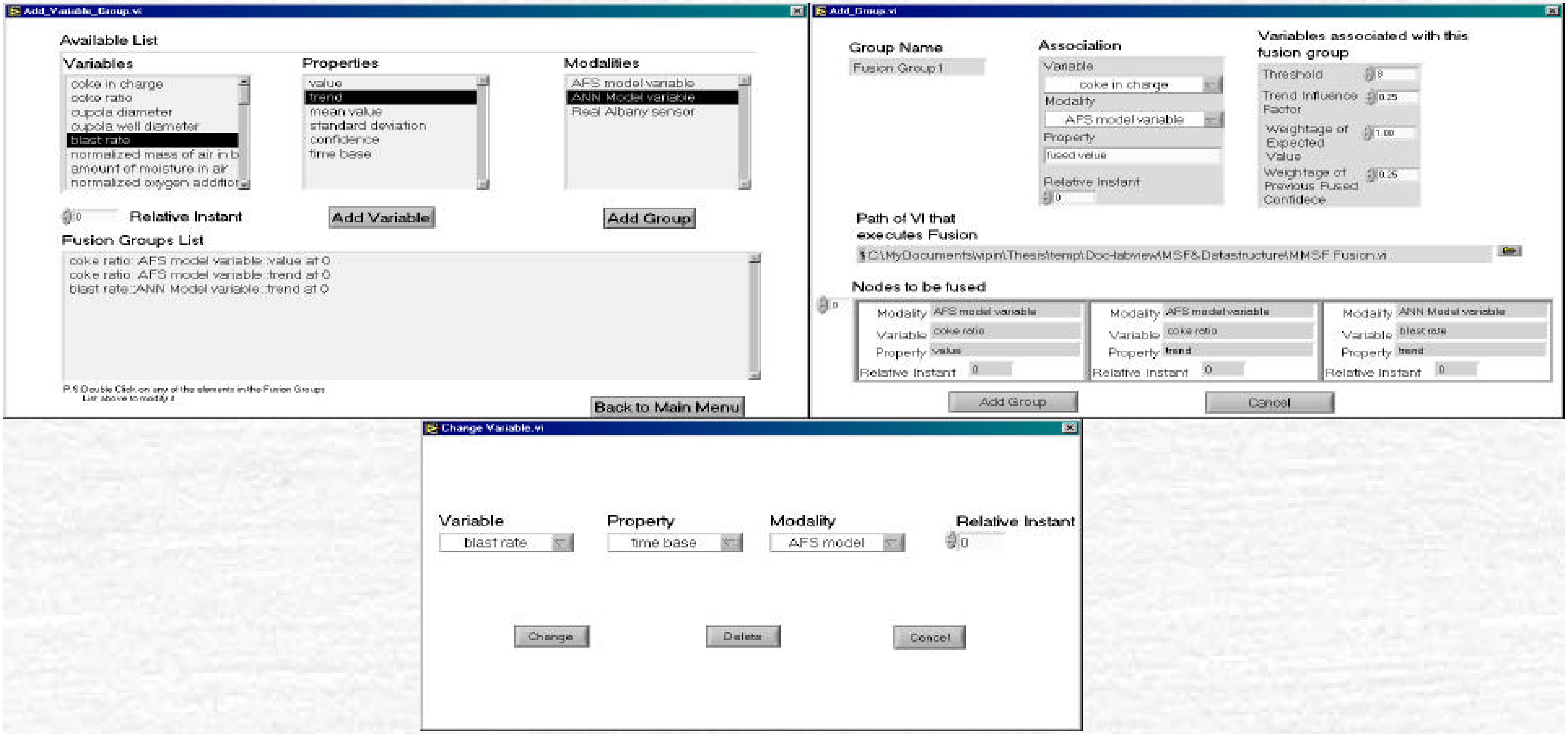
User Interface::System Setup...

Screens for Defining Variables, Modalities and Properties



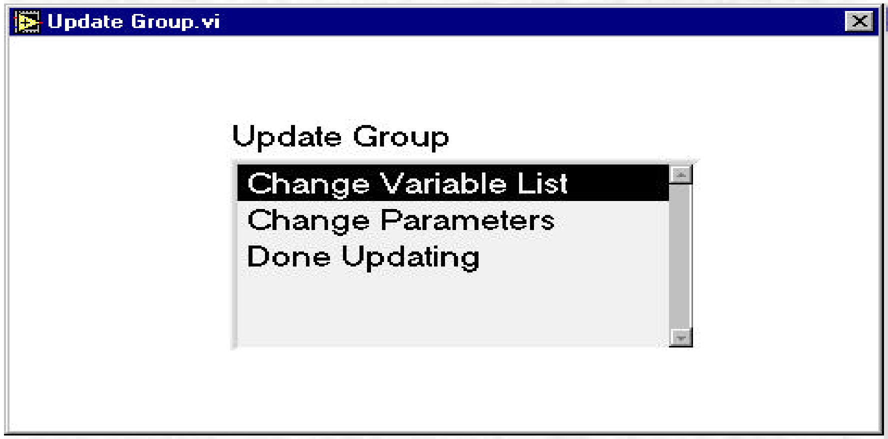
User Interface::Fusion Groups...

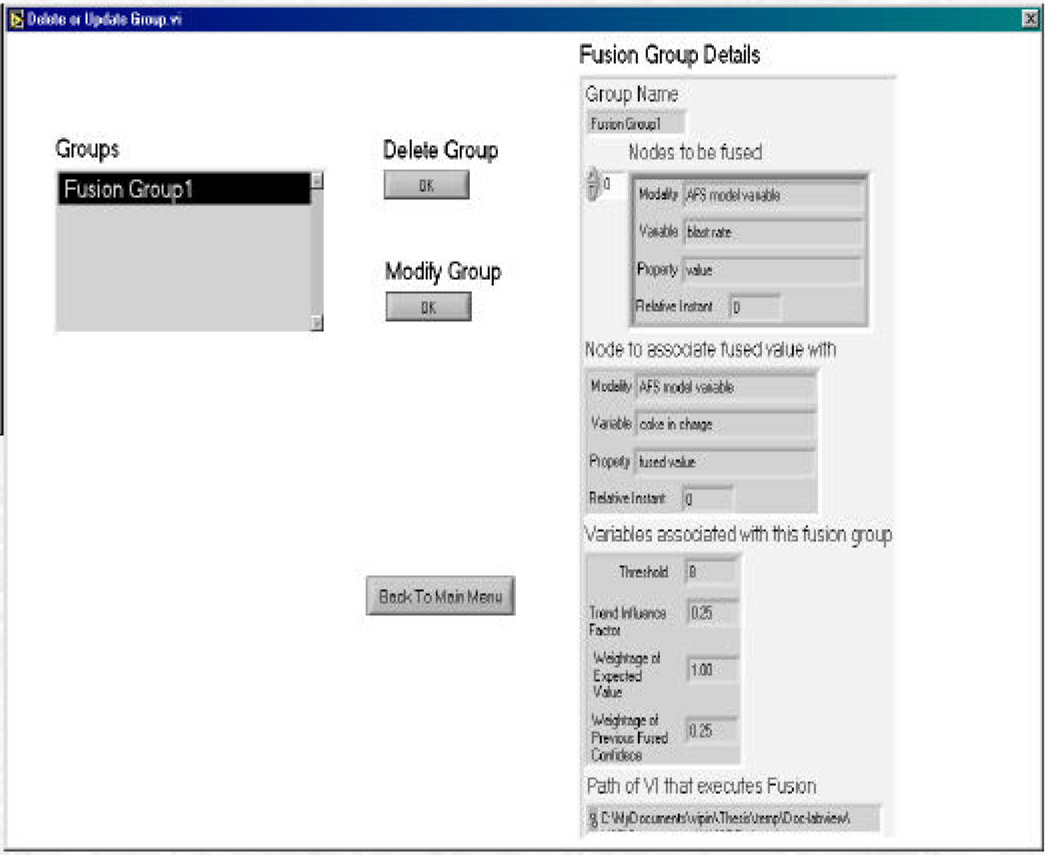
Create Fusion Groups



User Interface::Fusion Groups...

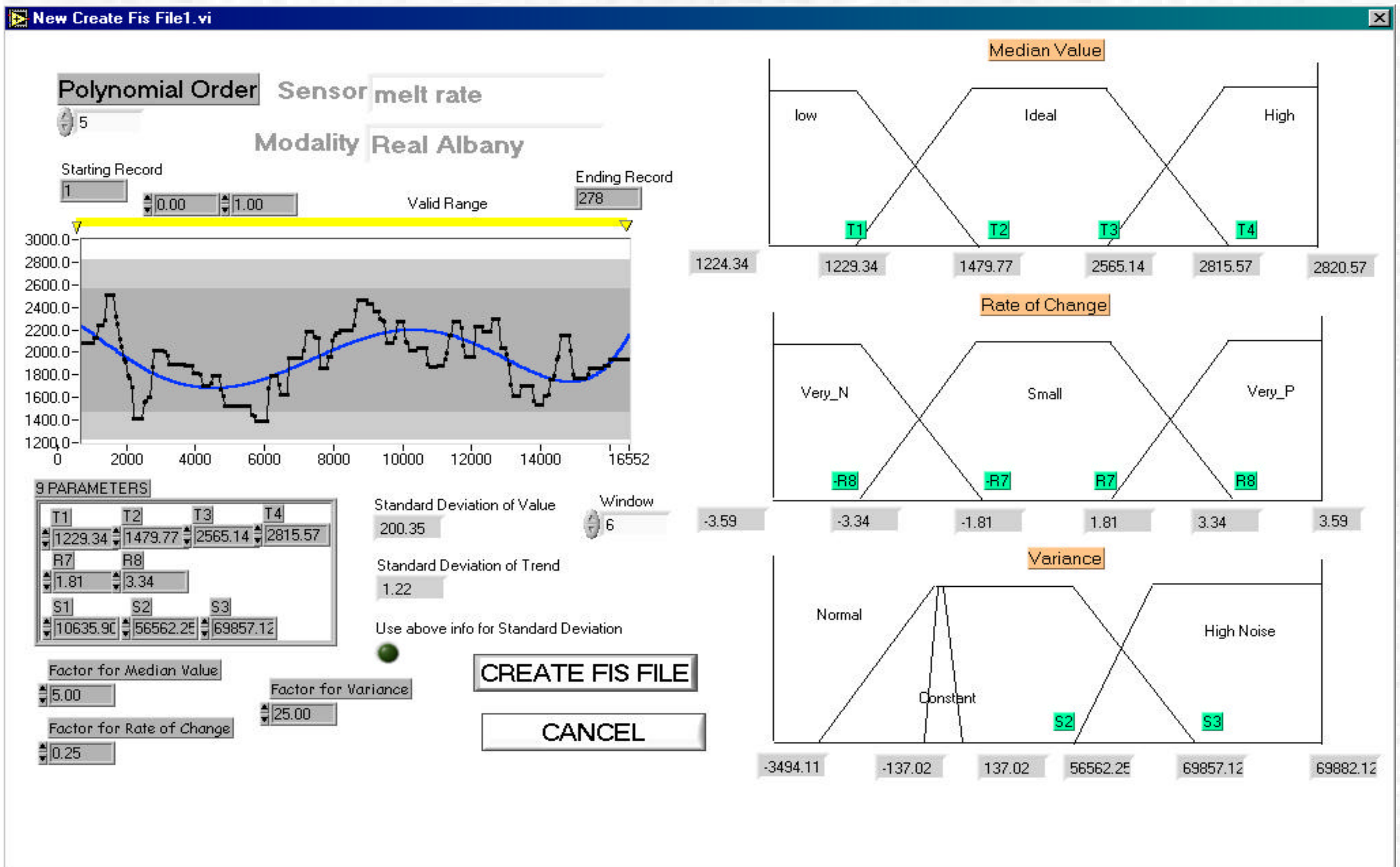
Edit Fusion Groups





User Interface::Sensor Parameters…

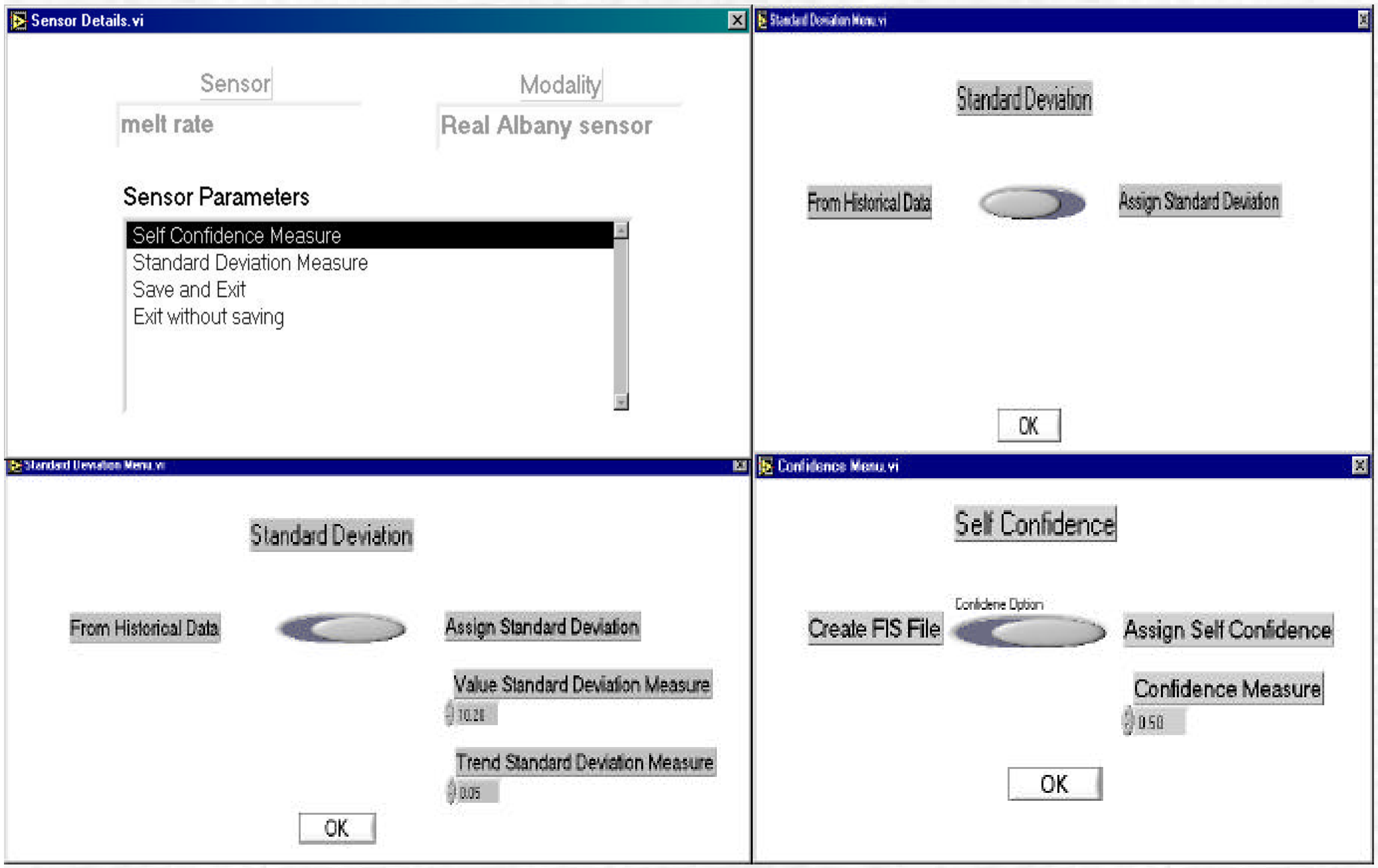
Interface to Setup Self Confidence Parameters



Uses Historical Data to Evaluate Self Confidence parameters

User Interface::Sensor Parameters...

Interface to Setup Self-confidence Parameters

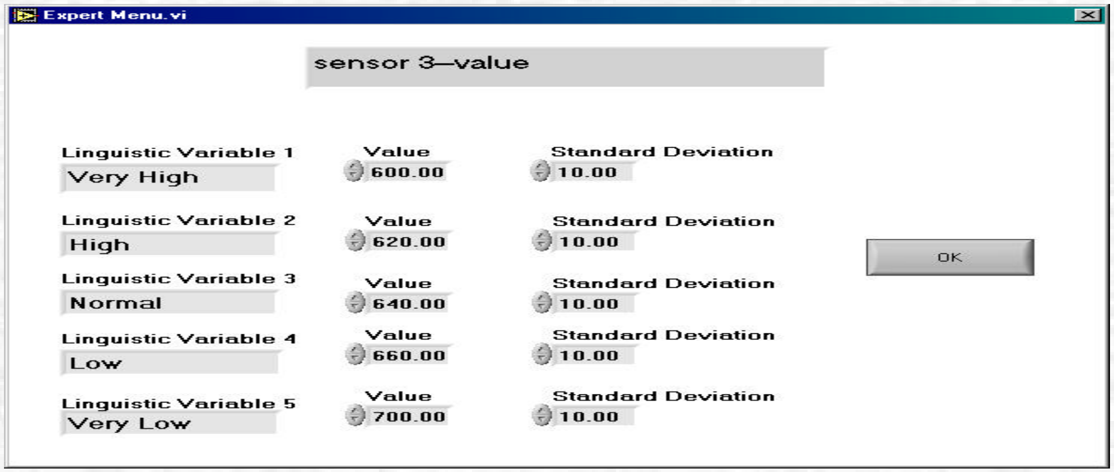


Screens Provide a User Override to automatic settings for self-confidence Parameters

User Interface::Expert System

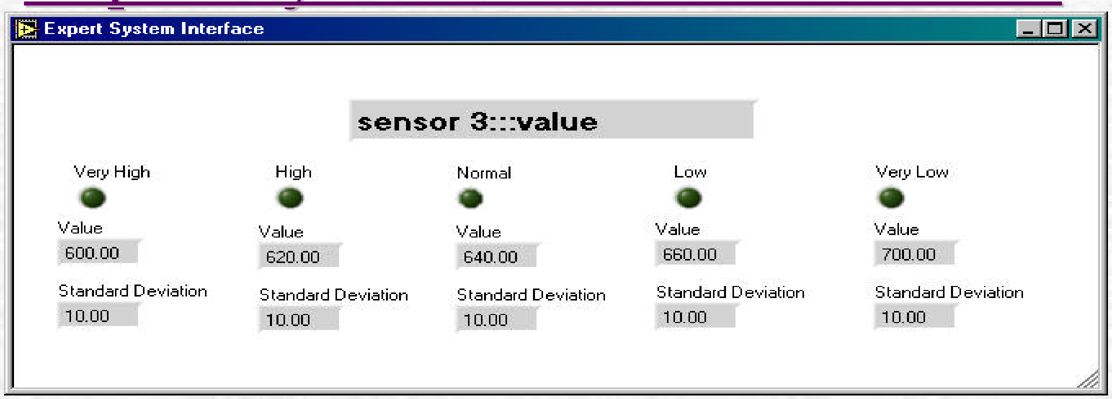
Expert System Setup

Setup Linguistic Ranges for an Operational System Variable

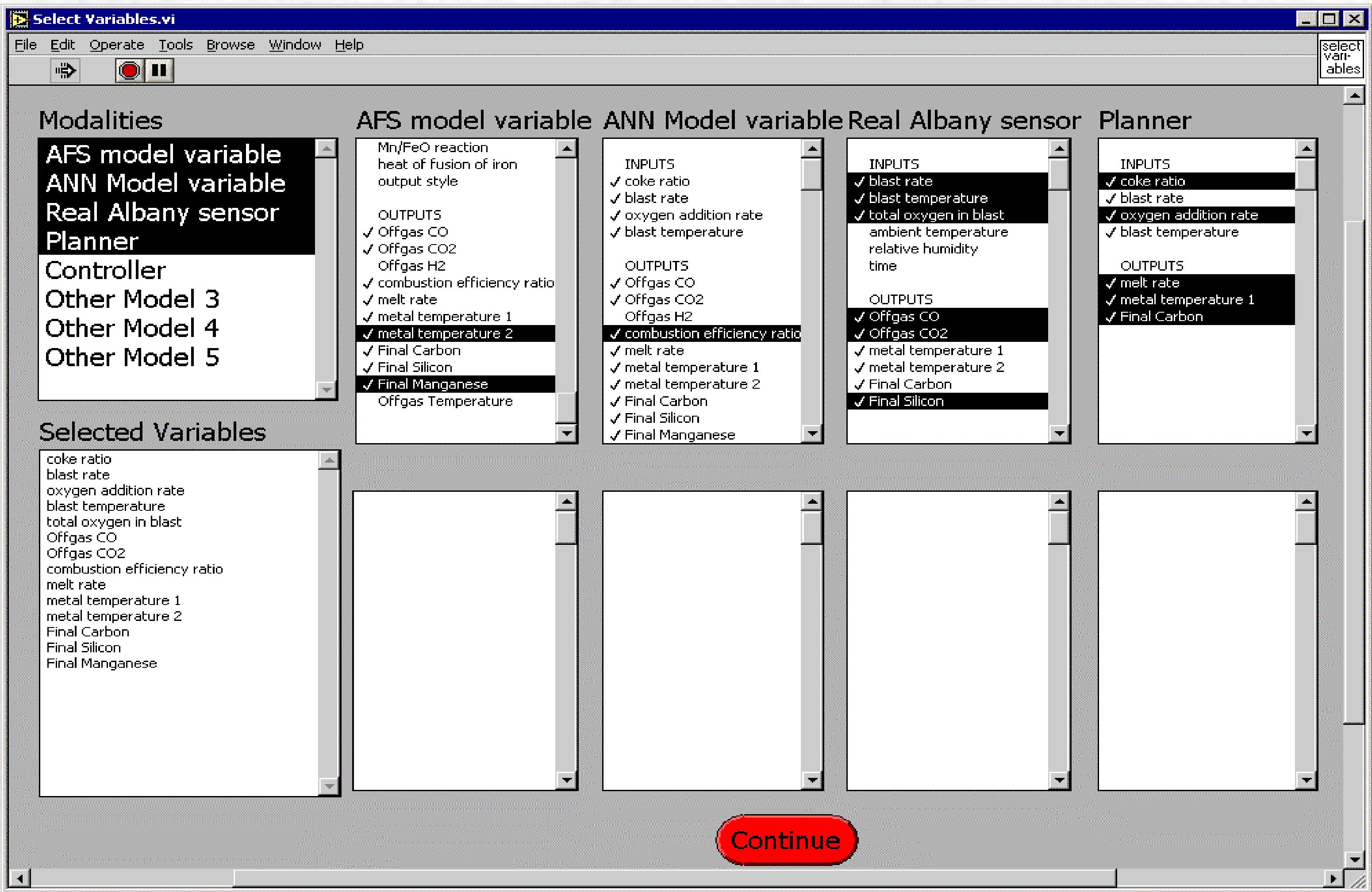


Expert System Run Time Interface

On Demand Run Time Screen for Operator Input



User Interface: Setup Modalities

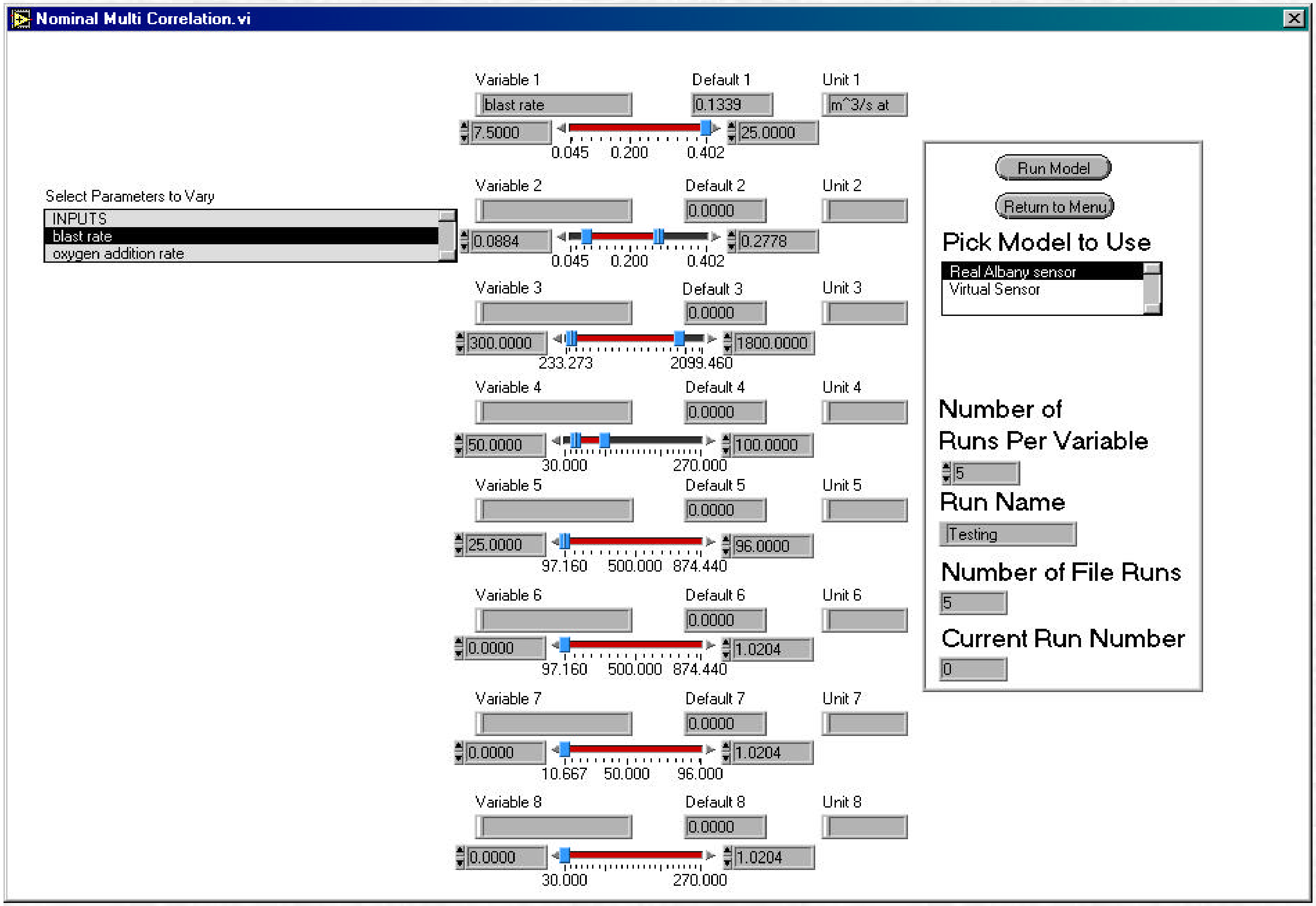


Variables from many different sources can be compared.

Selecting a variable in one model will also show that the same parameter in another model is also selected.

This setup also allows models to only use the variables that pertain to them, and not the entire set.

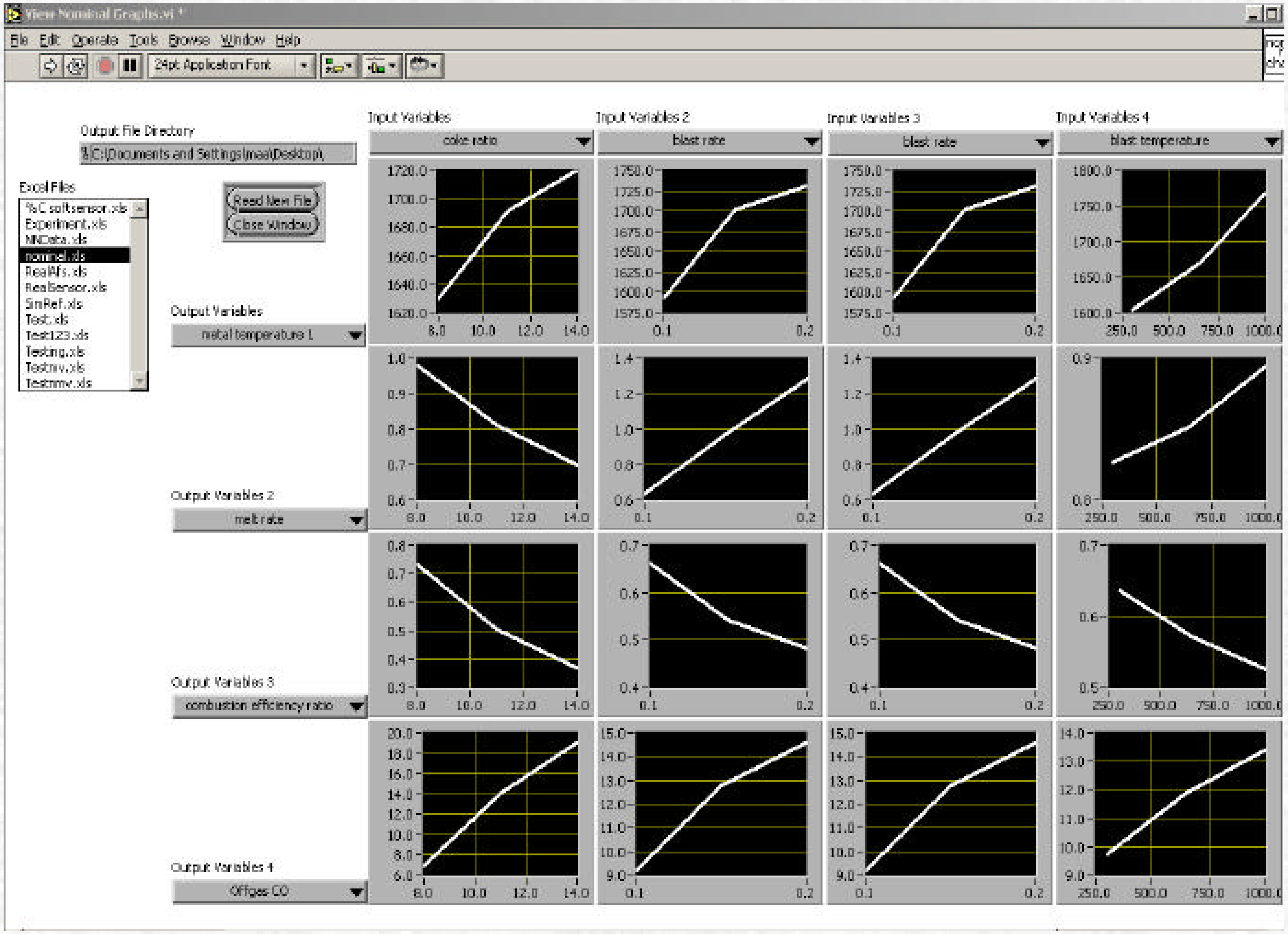
User Interface: Model Interrogator



Variables are chosen and a range defined for each.

The model is executed a number of times and the results are collected so that trends can be compared.

User Interface: Data Analysis- Model Interrogation



Analysis of relationship among various cupola Parameters using Model Interrogator with AFS Model

Simulation and Results

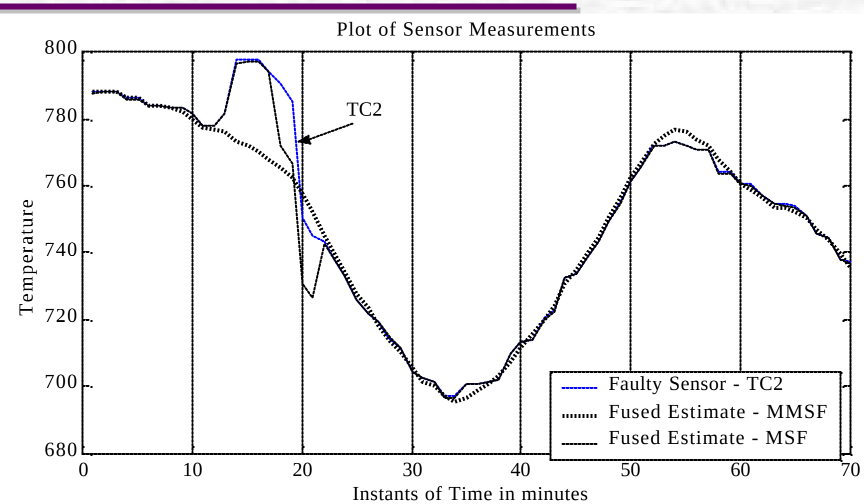
- Data for simulation : ALRC cupola
- Variables considered for testing
  - Melt Rate.
  - Iron Temperature.
  - Water Drum Temperature.
- Modalities considered for testing
  - Real Albany Sensors (Pyrometers, MR and Thermo couples)
  - Virtual Sensors (ANN Inferential sensors)
  - Expert Source

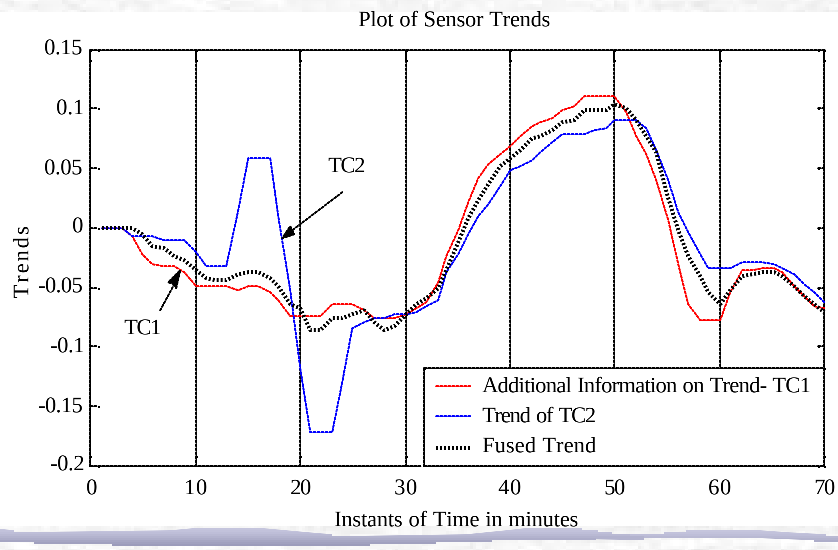
Simulation and Results...

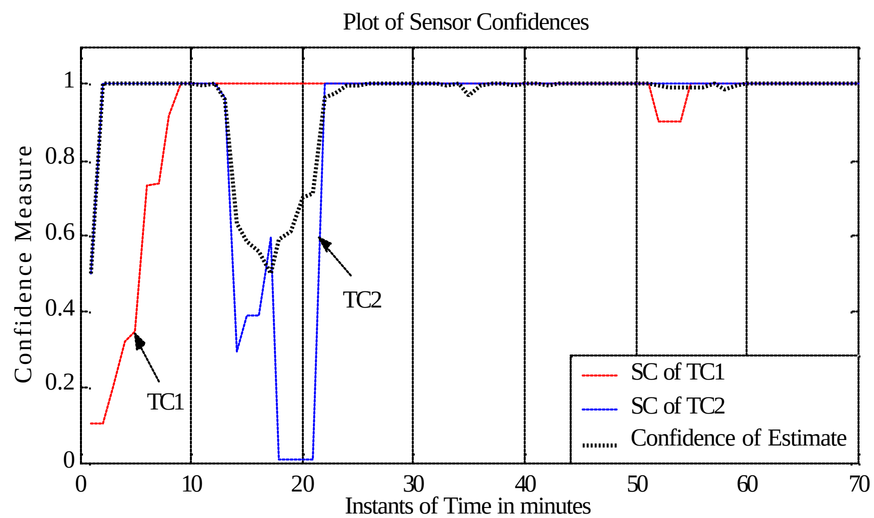
Thermocouples:Case2

Simulation Parameters:

- TIF = 0.25
- PVC = 0
- EVI = 1.5

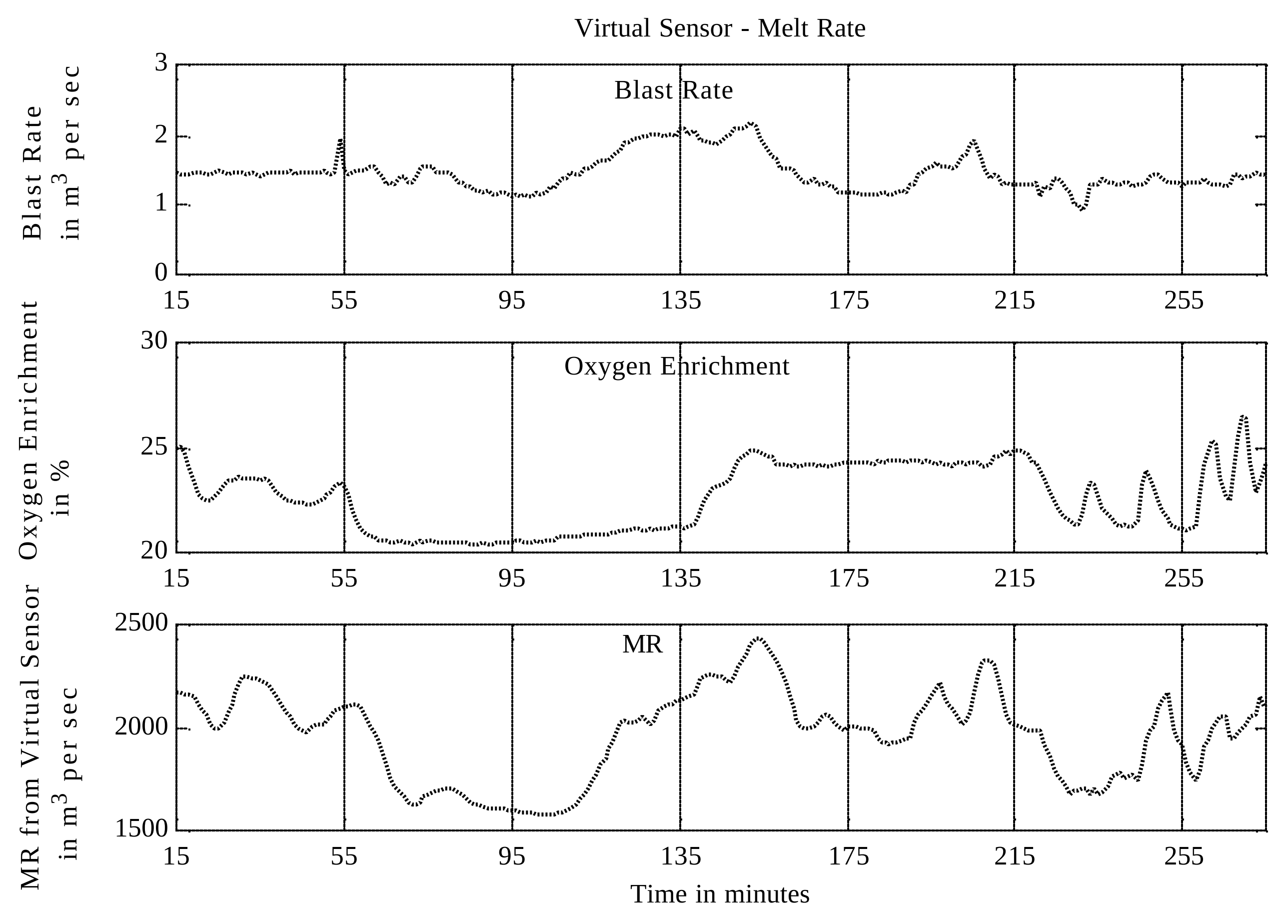






Simulation and Results…

Melt Rate Virtual Sensor

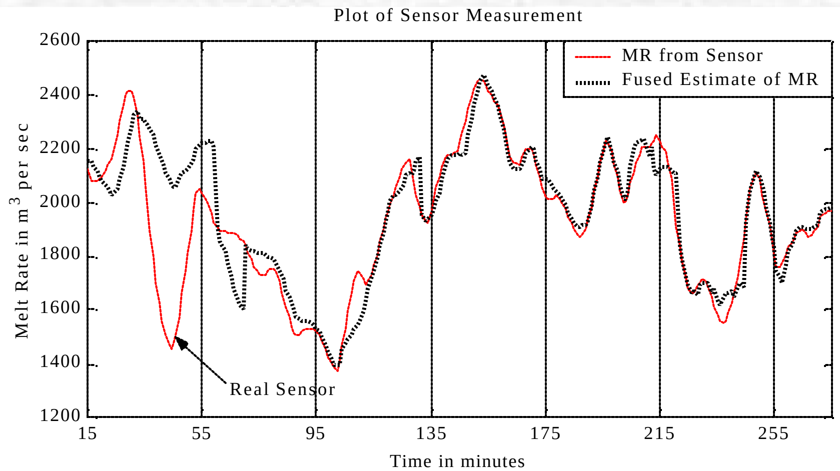


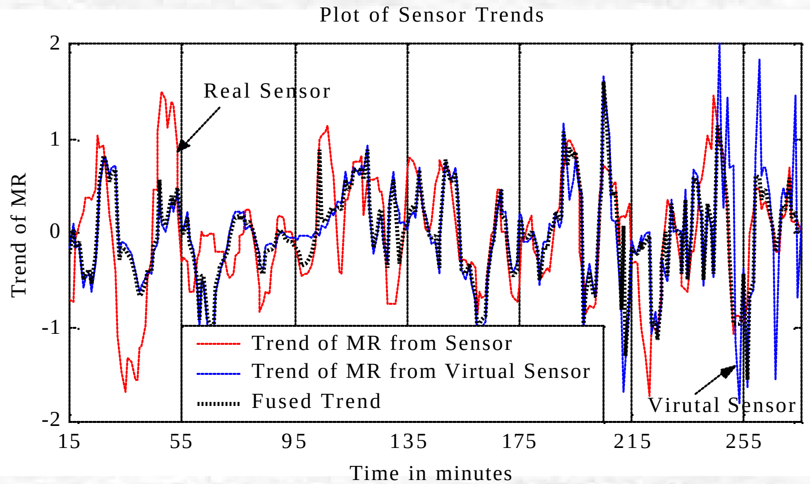
Simulation and Results...

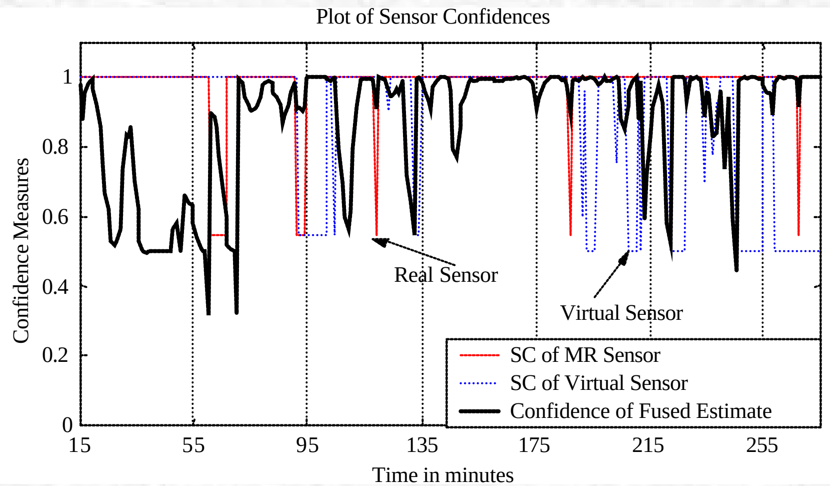
Melt Rate:Case1
Virtual Sensor as Trend Source

Simulation Parameters:

- TIF = 0.10
- PVC = 0.75
- EVI = 1.5





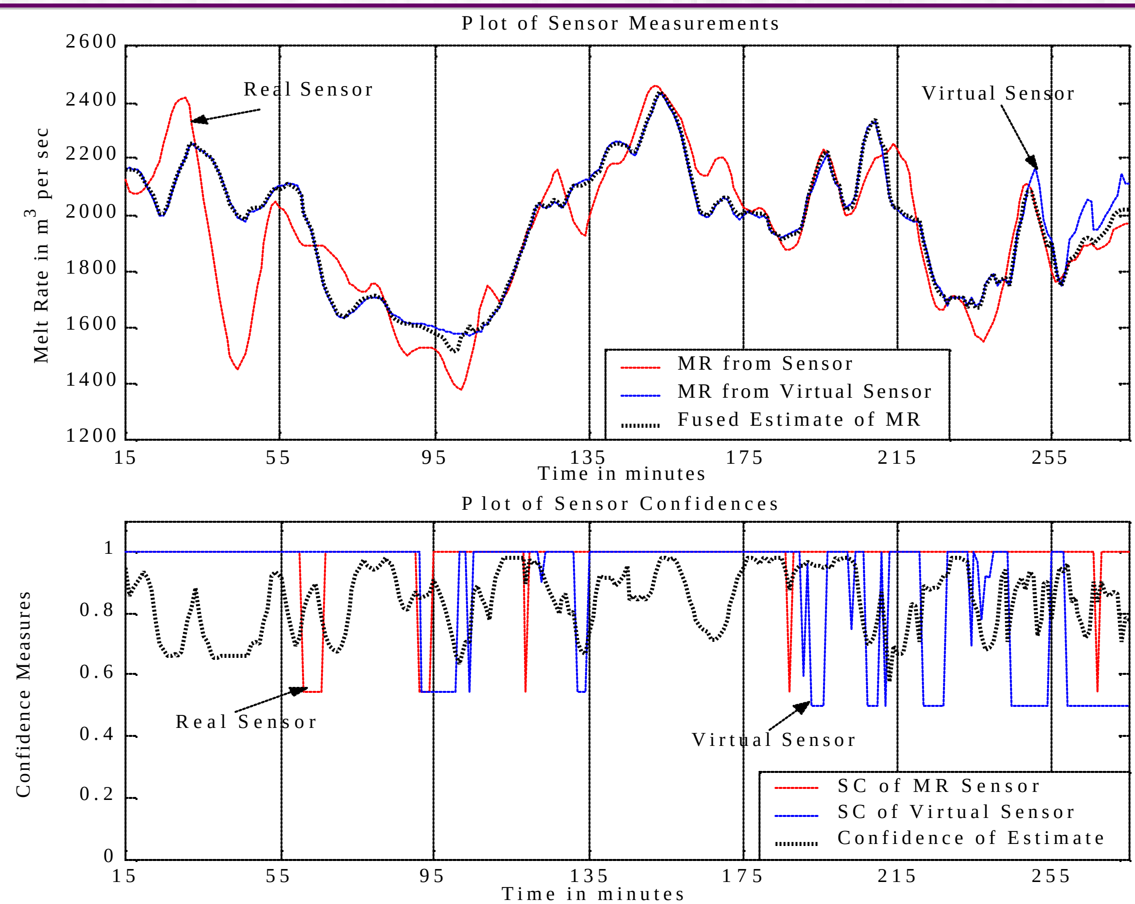


Simulation and Results…

Melt Rate:Case2 Virtual Sensor as Trend and Value Source

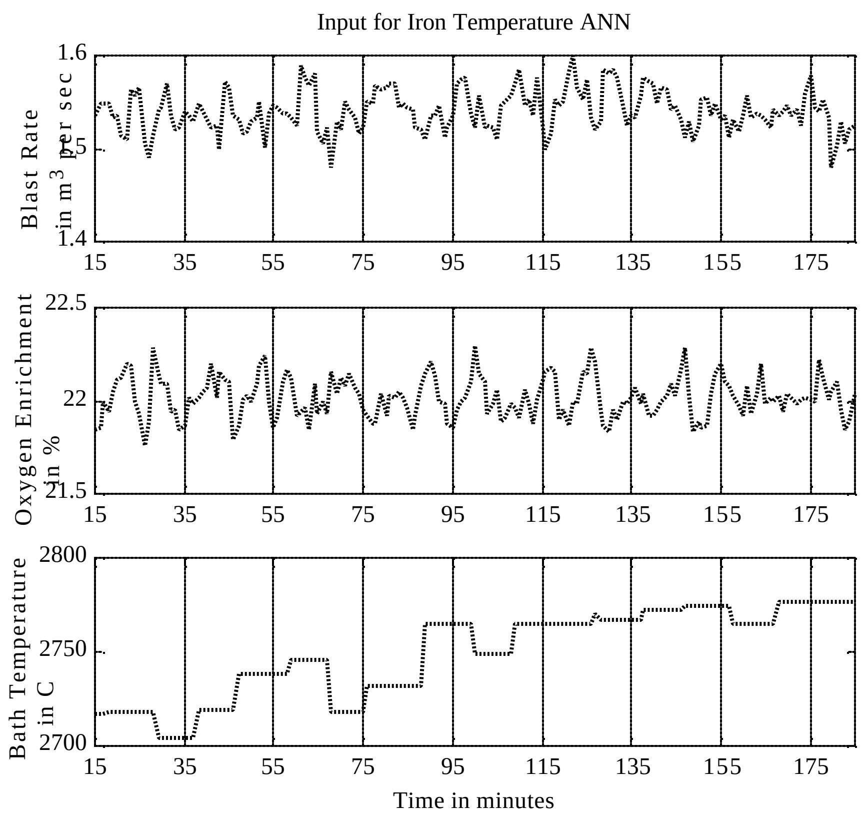
Simulation Parameters:

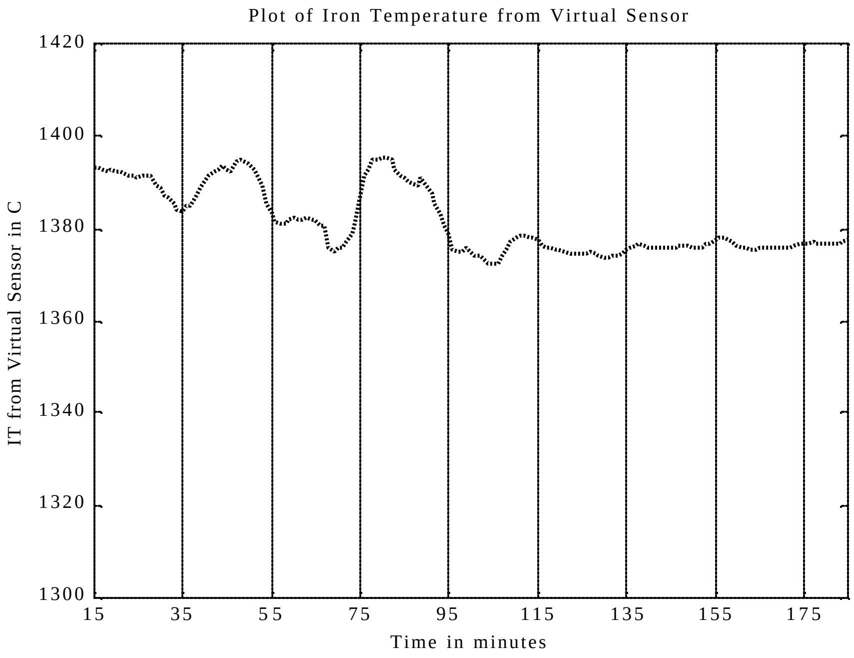
- TIF = 0.25
- PVC = 0
- EVI = 1.5



Simulation and Results...

Iron Temperature Virtual Sensor





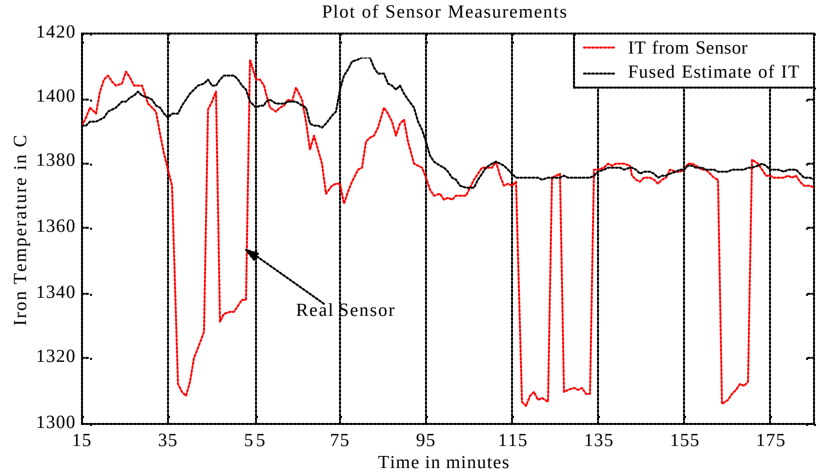
Simulation and Results…

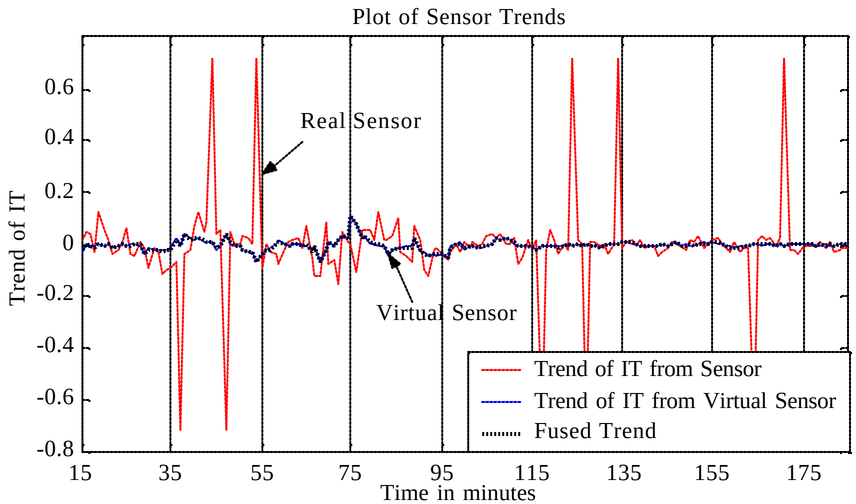
Iron Temperature:Case1

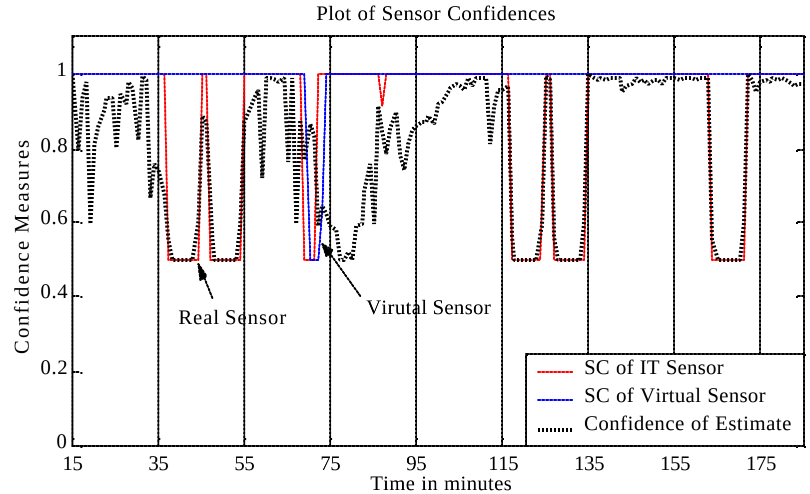
Virtual Sensor as Trend Source

Simulation Parameters:

- TIF = 0.25
- PVC = 0
- EVI = 1.5





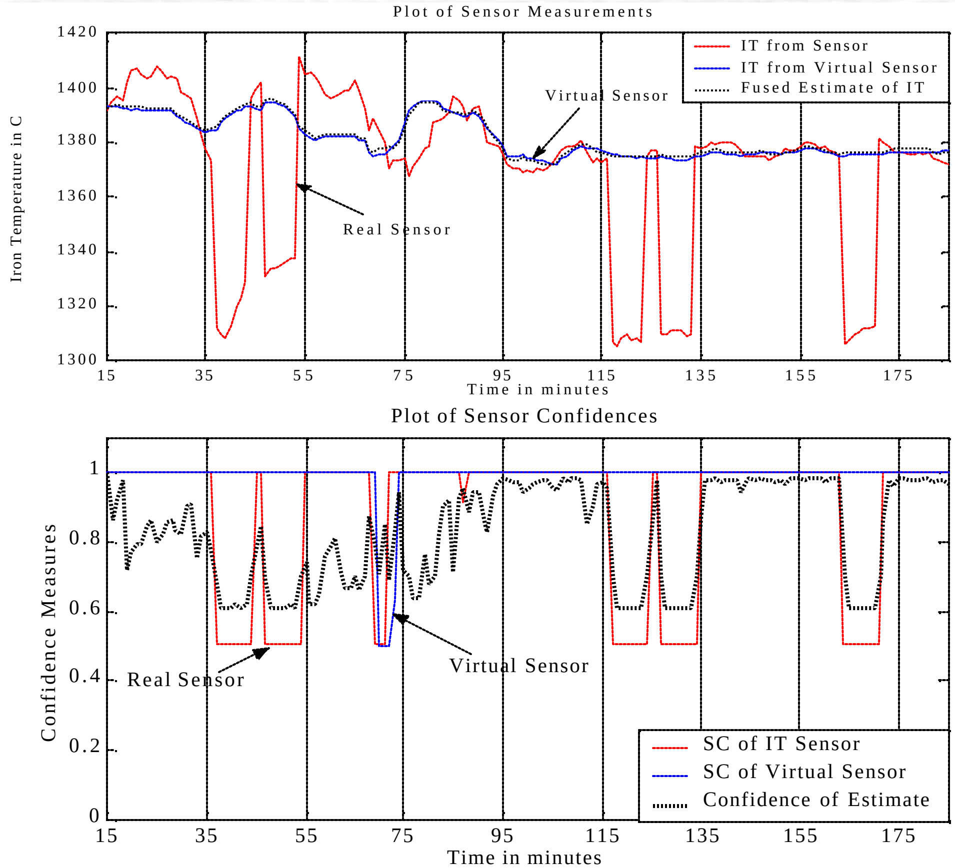


Simulation and Results…

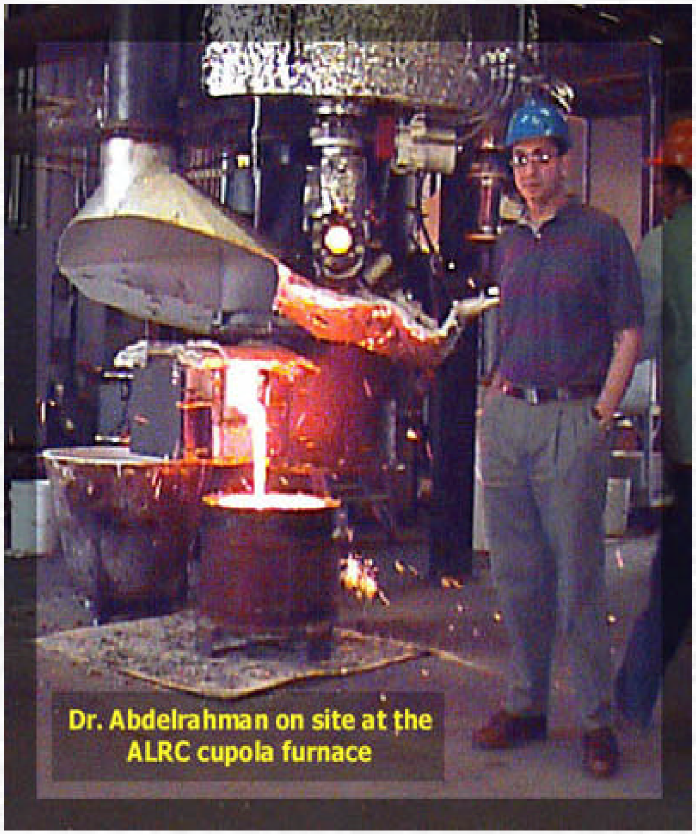
Iron Temperature:Case2 Virtual Sensor as Value & Trend Source

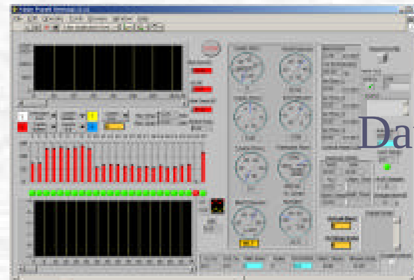
Simulation Parameters:

- TIF = 0.25
- PVC = 0
- EVI = 1.5



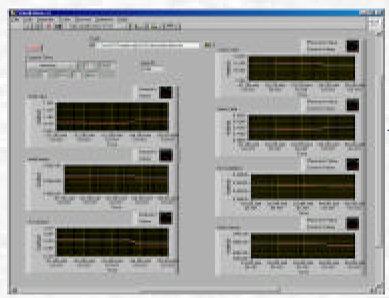
Demonstration Plans





Data Acquisition Software
on cupola computer

Ethernet
interface

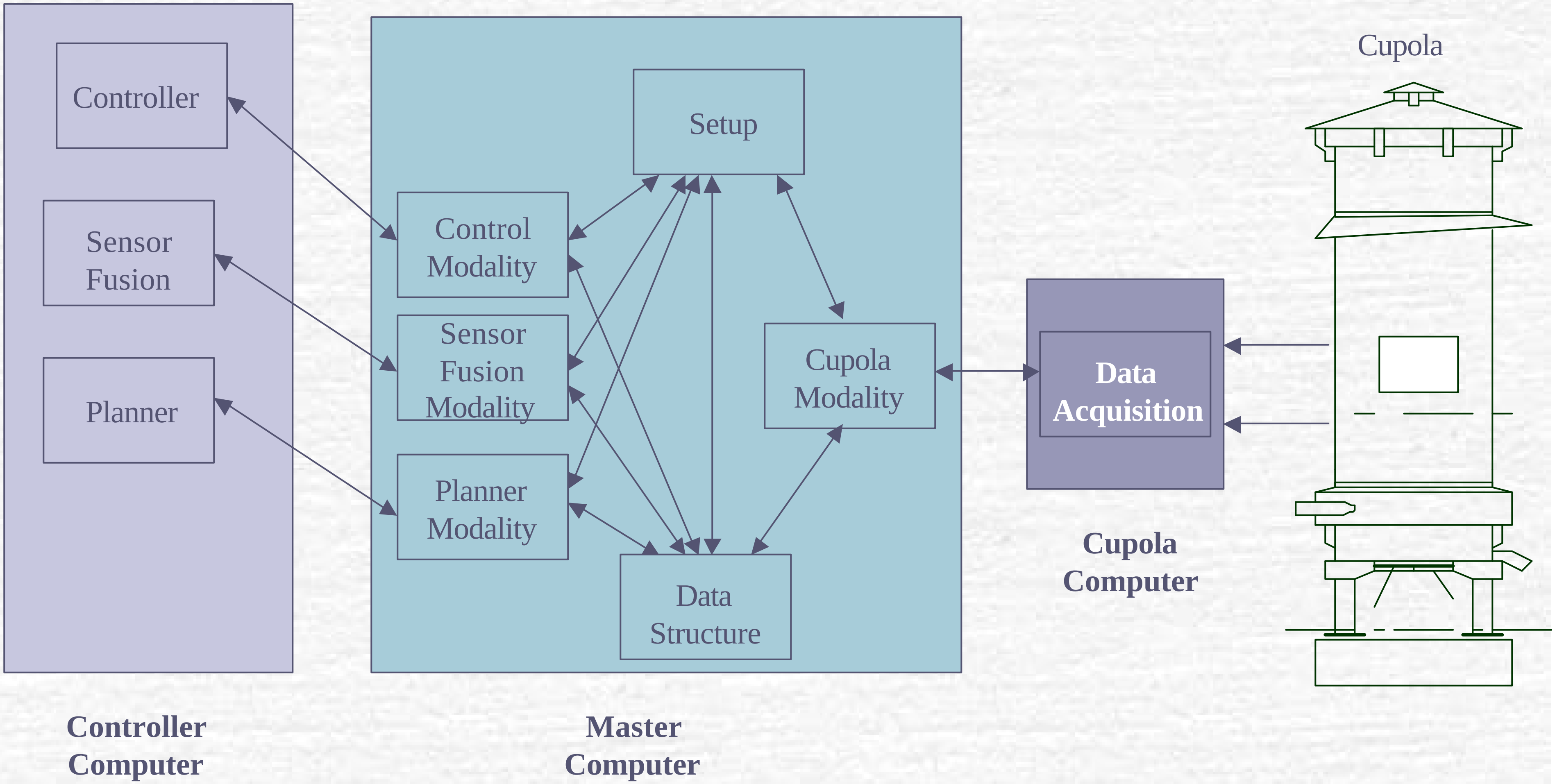


Sensor Fusion,
Planner and
Controller

Ethernet
interface

Data Structure on
Master Computer

Computer Architecture for Demo Plans



Demo Plans

- Independent Control of Molten Iron Parameters (Melt rate, Temperature and Iron Composition) under practical situations suggested by Industrial Advisory Board.
- Testing Performance of Virtual Sensors and Fusion Algorithms.

What has been Accomplished So Far?…

- Interfacing with Computer System in Albany Research Center,
- Preliminary Planner and Cupola Controller
- A Pool for Selection of Demonstration Plans in Consultation with Industrial Advisory Board.

What has been Accomplished So Far?

- A Methodology for Multi Modal Sensor Fusion (Best Estimate, Confidence in the Estimate)
- A Generic Open Architecture that allows for Easy System maintenance and reconfiguration and Distributed Computing,
- A Generic Model Interrogator with special focus on AFS Cupola Model (Data Analysis, Expert Rules, Operator Training),
- GUI for Setup of System Components

Future Work

- Complete Development of Intelligent Controller
- Preparation for Demo Plans in September, 2001
- Continue Testing & Debugging
- Complete System Integration
- Marketing the Technology