Neural-Network Control in the Metals Industry

Edward Wilson

Systems Alternatives, Inc.

http://www.sysalt.com

ed.wilson@alum.mit.edu

Outline

- Our approach - what we've found useful, examples
  - Spacecraft control application
  - Electric Arc Furnace control (steelmaking)
  - Green Sand controller (casting)
- Needs in industrial NN control
- Research suggestions

Approach, Philosophy

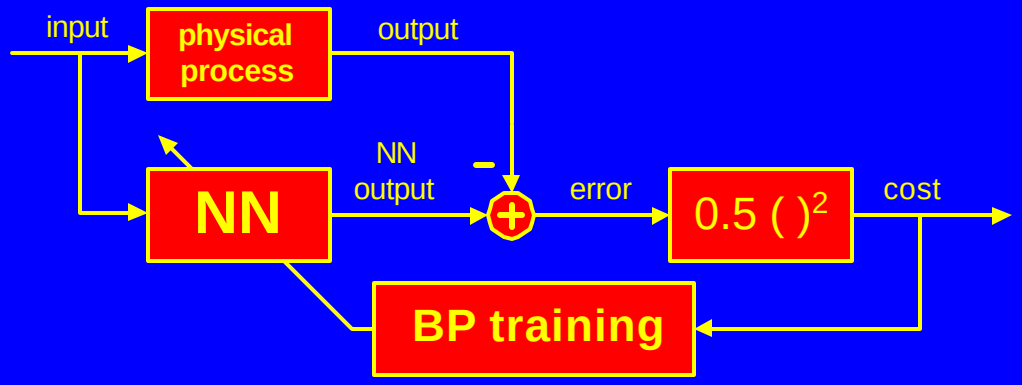
- NN's capabilities (nonlinear, adaptive, generic, parallel hardware) must be considered against costs (nonlinear optimization, black box, no stability proof)
- Use NN as part of well-designed system. System architecture and targeted use of NN more important than NN-specific issues.
- Expect significant pre-processing effort.
- Staged development approach: (1) fixed linear, (2) adaptive linear, (3) adaptive nonlinear (neural)

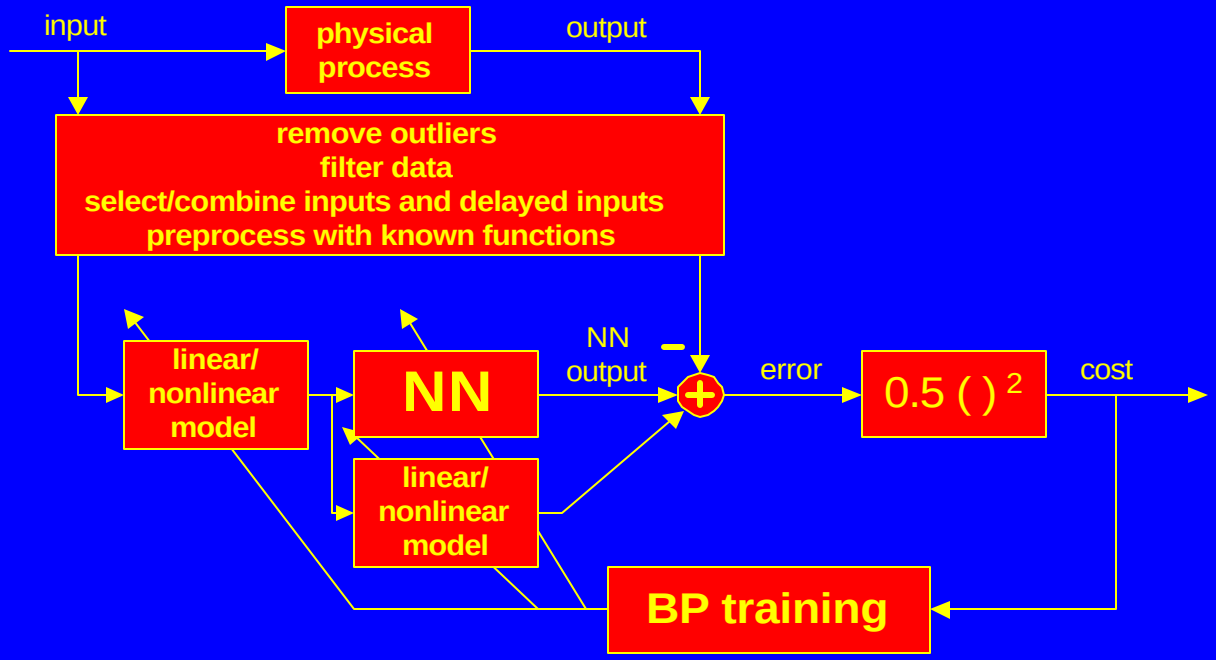
NN Training = GBPO

- NN training (using BP) is a special case of gradient-based parameter optimization
  - BP efficient for finding derivatives
  - Generic nonlinear aspect of NN valuable
  - Parallel hardware implementation is possible
- Parameter identification issues present in ARMA modeling, etc. are present here:
  - sample rate
  - sufficient data
  - minimal but sufficient d.o.f. in model
  - data pre-filtering
  - selecting tapped-delay-line inputs
  - outliers
  - etc.

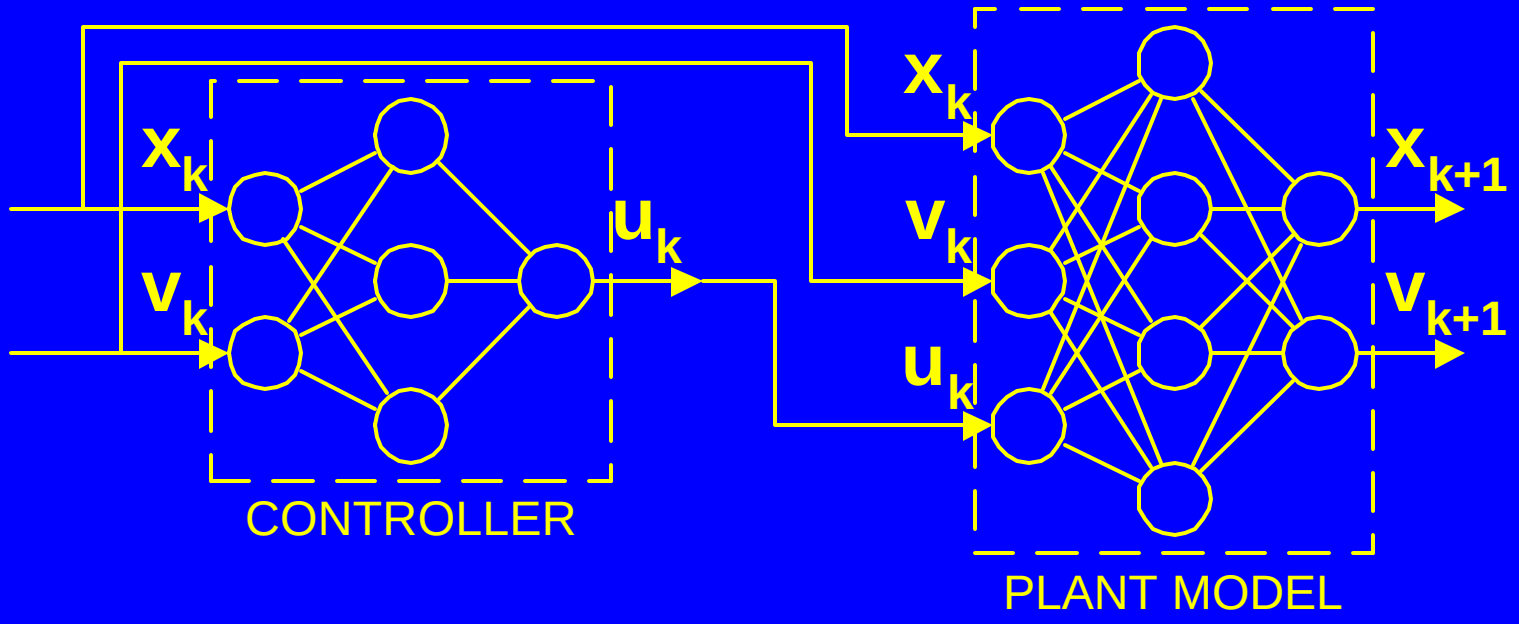
Details of Direct Training

- Significant effort in preprocessing data, structuring NN / linear / nonlinear model - use known structure to extent possible
  - e.g., linear + polynomial + NN
  - allows input of pre-calculated solutions



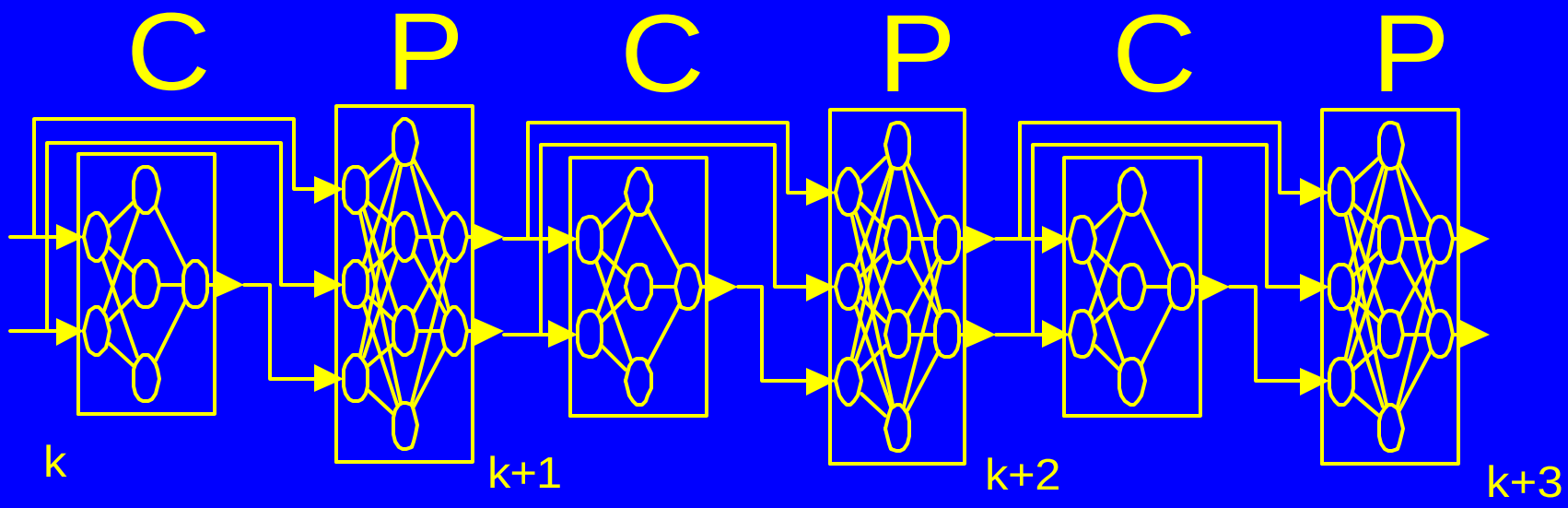


Indirect Training - Controller Optimization



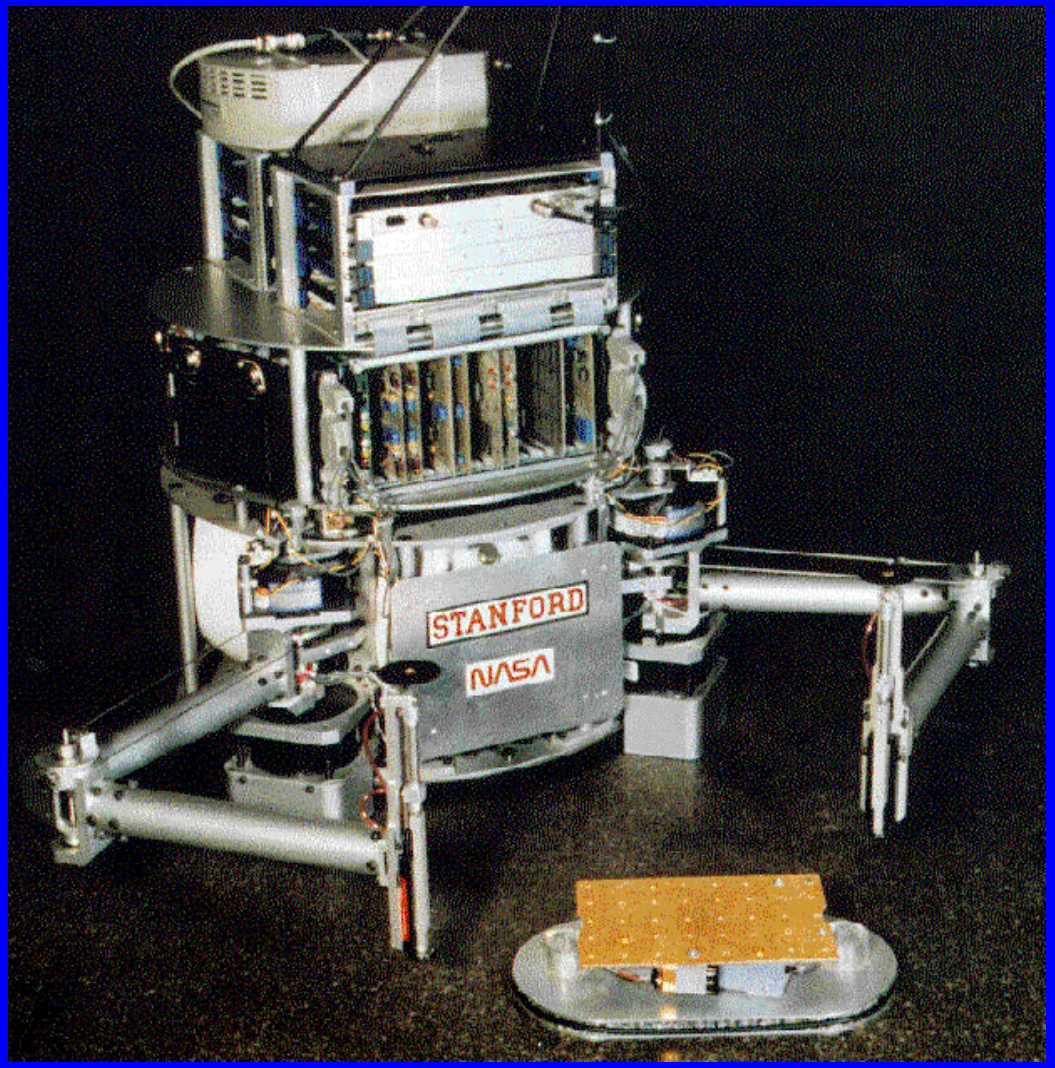
- Plant model is fixed (adapted separately to model plant data)
- Calculate cost function, $f(u_k, x_{k+1}, v_{k+1})$
- BP to get derivatives, optimize weights in controller
- Requires direct, continuously differentiable path from control parameters to cost calculation

Controller Opt. - LQR, terminal

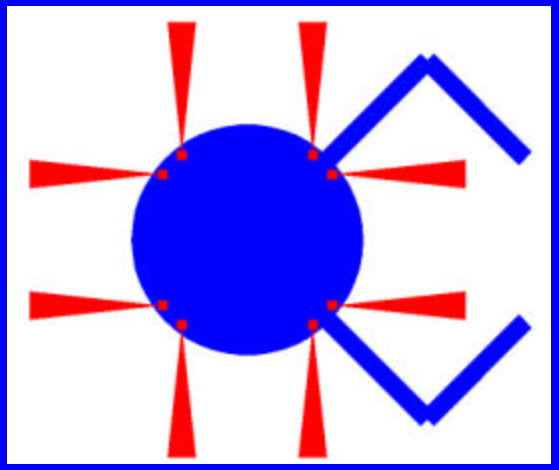


- “Backpropagation through time” - copies controller (C), plant (P)
- Cost on terminal state, intermediate states, actuators, etc.
- BP to find derivatives of cost w.r.t. controller parameters. Then optimize.

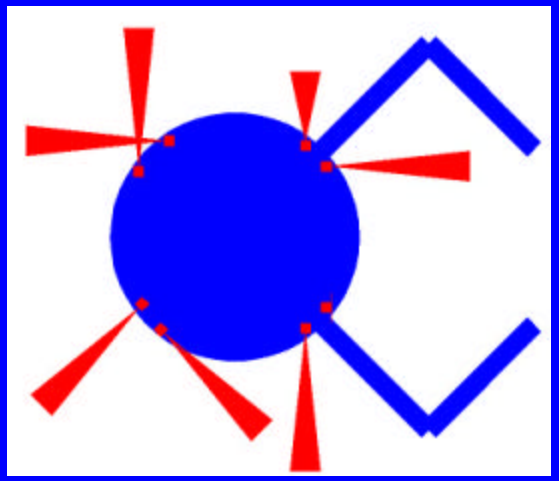
Space Robot Control Example



Stanford free-flying space robot
- Stanford Aerospace Robotics Laboratory

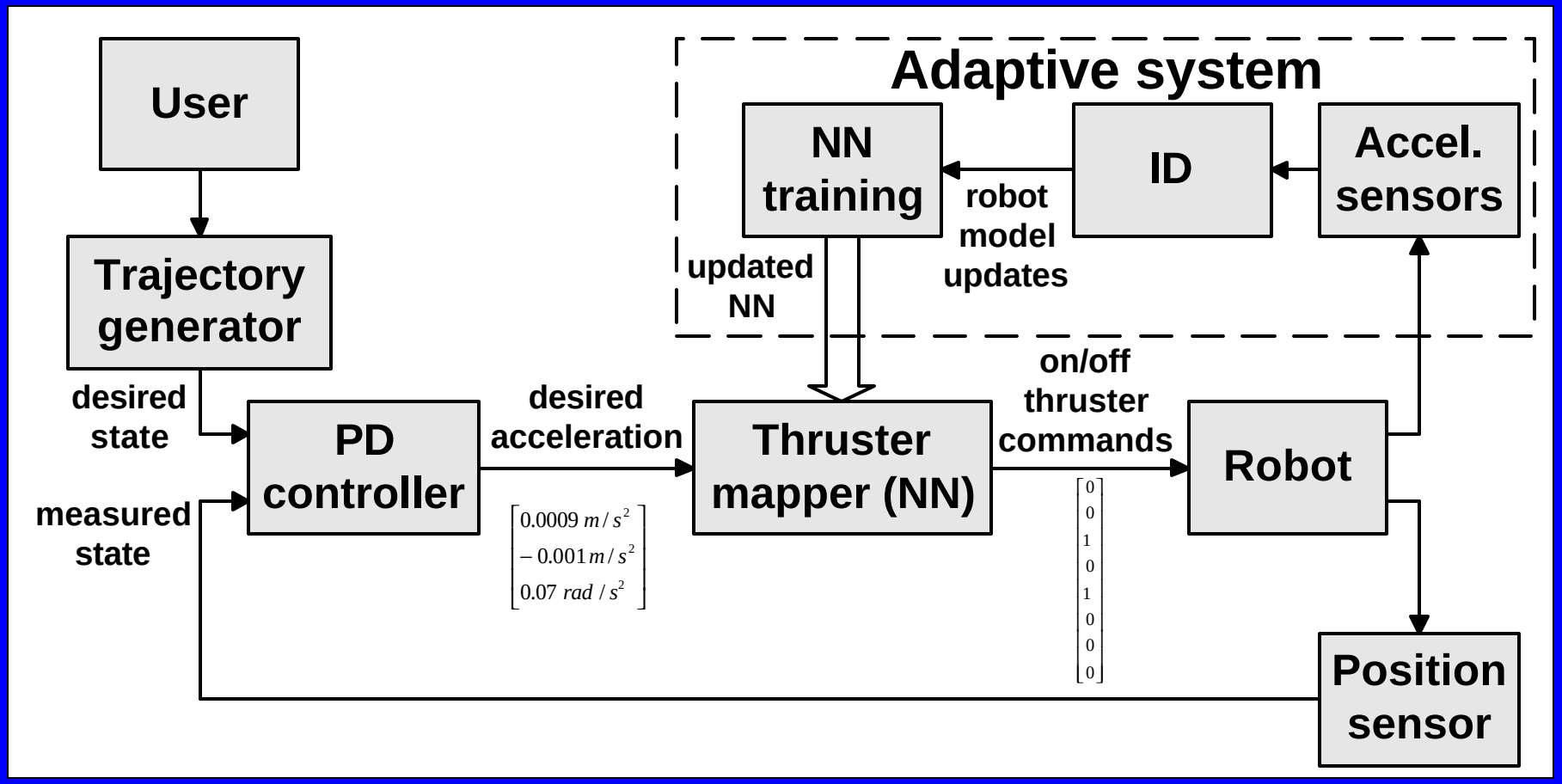


Nominal thruster configuration



After multiple unknown failures
(some destabilizing)

Thruster Control Architecture

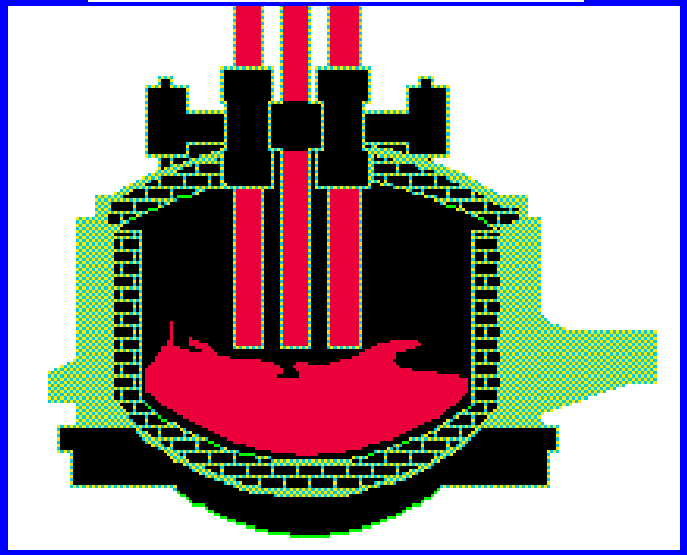


- Standard indirect adaptive control architecture
- NN is used exactly where benefits outweigh costs

Intelligent Arc Furnace Controller

NEURAL® APPLICATIONS CORPORATION

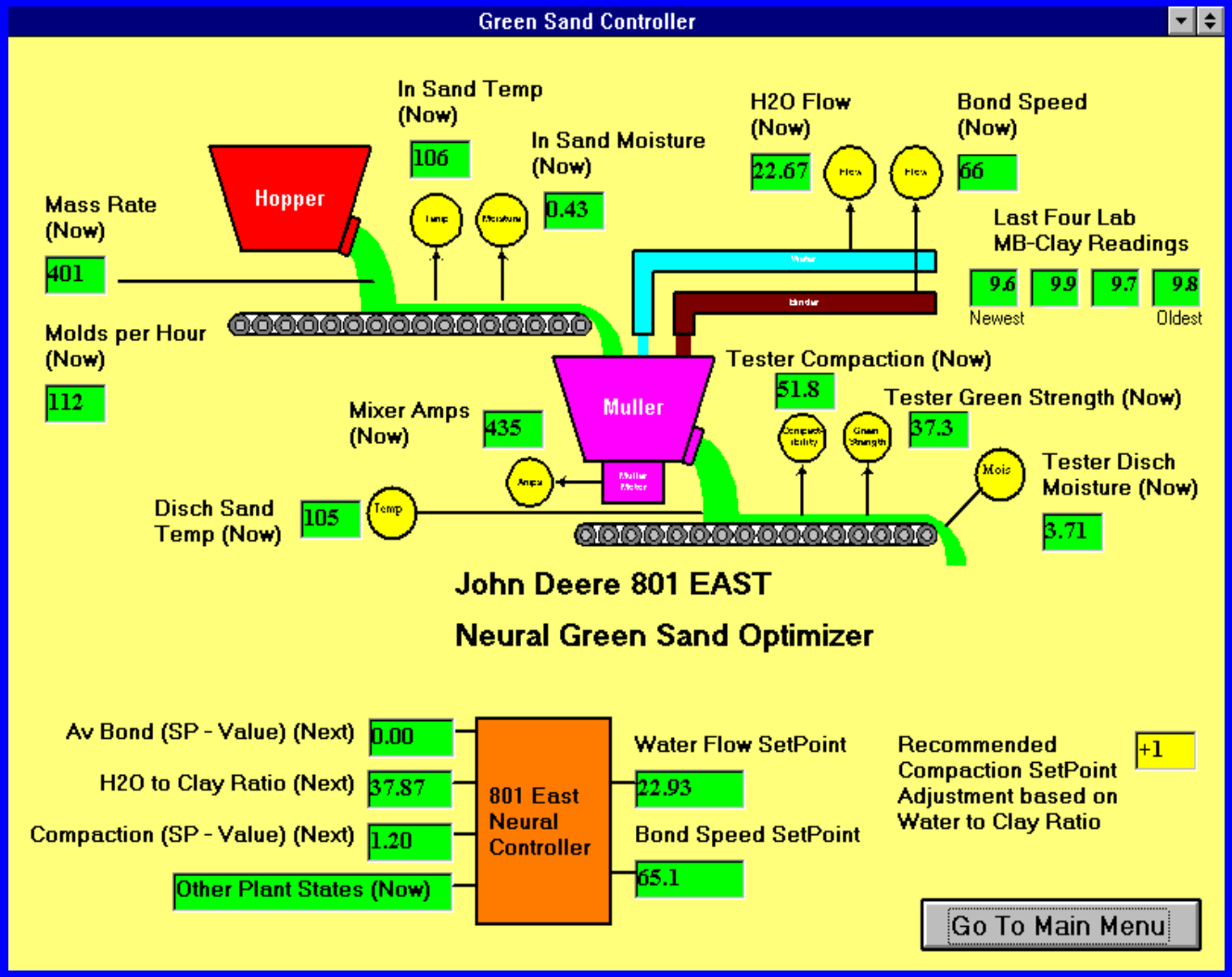
Intelligent Arc Furnace™ Controller



Reduces production costs:
- less energy
- less electrode consumption
- increased throughput

- NN-based regulation system for control of electric arc furnace, used in steelmaking
- Uses backpropagation, similar to generalized predictive control architecture
- Adapts to changes in system dynamics and scrap being melted
- Data availability outweighs process understanding
- 40 installations worldwide - each one is different
- Sale price ~$300,000

Green Sand Controller



- NN predicts process output to account for transport delay - used as “virtual sensor”

When, How to Apply NNs

one liner: “Use NN when data availability outweighs process understanding”

- Cost / benefit analysis
- Evaluation of “conventional” methods
- Use NN where these fall short
- Structure total solution to use NN in conjunction with these
- Build up from fixed linear system ==> adaptive NN

Needs in Industrial NN Control

- Tools to improve architecture selection, input selection
- Reduce the number of parameters (e.g., learning rate, momentum, architecture, # taps, etc.)
- Faster optimization is generally not an issue
- Deal with realities of industrial control
  - sensor/actuator degradation or failure
  - form of dynamics may not be clear (# taps, transport delay, etc.)
  - relatively limited data, as compared to noise level and response time requirement
  - presence of noisy (non-Gaussian, non-white) data
- Desirable for solution to be tied closely to classical approach - Black Box issue is a problem

Research Suggestions

- Problem: Empirical nature of research results
- Solve a particular real problem with real data (and issues from previous page) if possible
- Solve first using best available, non-NN, methods (staged development approach if possible)
- Then value of NN can be evaluated fairly

Summary

- Our approach
  - Overall control architecture design, careful selection of NN application area important
  - Staged implementation: linear => adaptation => NN
  - Leads to control-based solution vs. pure NN approach
- Specific needs for industrial control
  - device failures, non-ideal noise, unknown model structure (as compared to robotics, for example)
- Suggested Research
  - Real problems, real data if possible
  - Fair comparison of NN with best available methods