Motor Control with Arduino

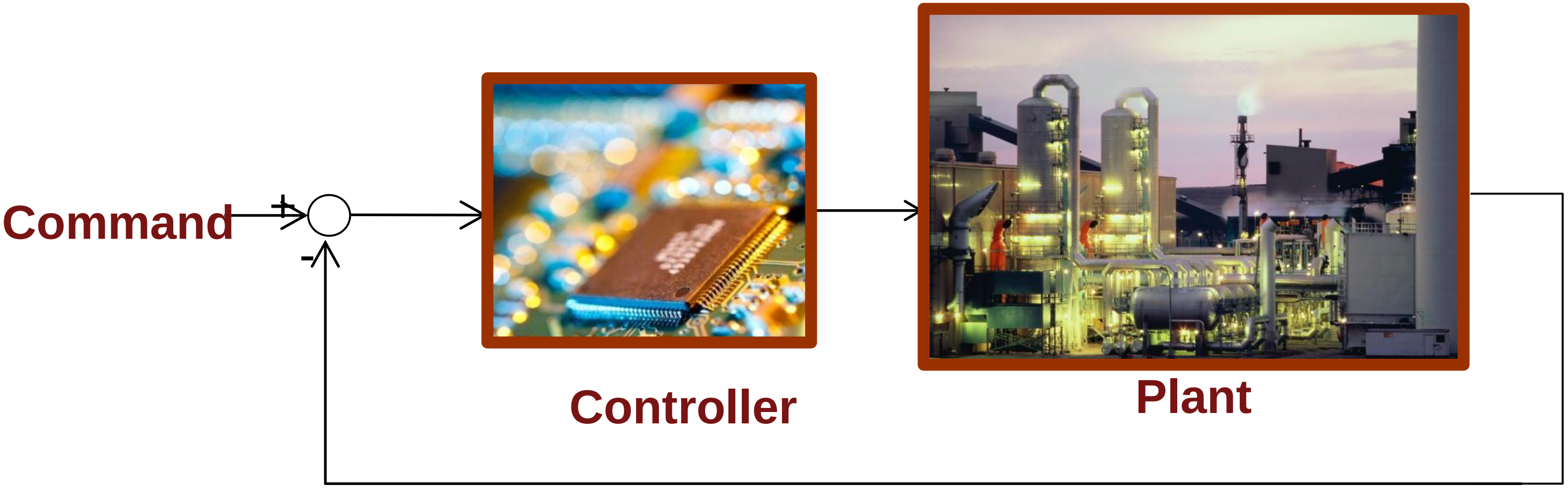
A Case Study in Data-Driven Modeling and Control Design

Toledo, 22-II-2013

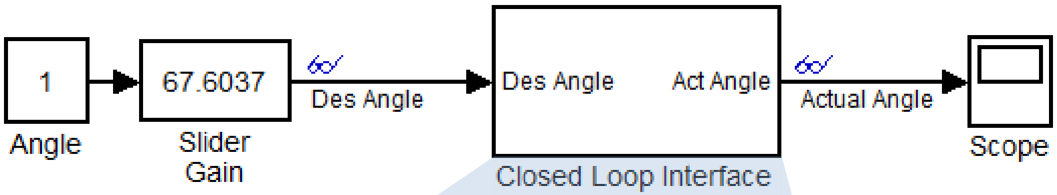
Why Data-Driven Control?

- Two approaches to modeling
  - **First-principles:** requires knowledge of math / physics of the system
  - **Data-driven:** requires measured input-output data

- Modeling from first-principles can get challenging



Demo: DC Motor Controller using Arduino Uno



1

Angle

67.6037

Slider Gain

Des Angle

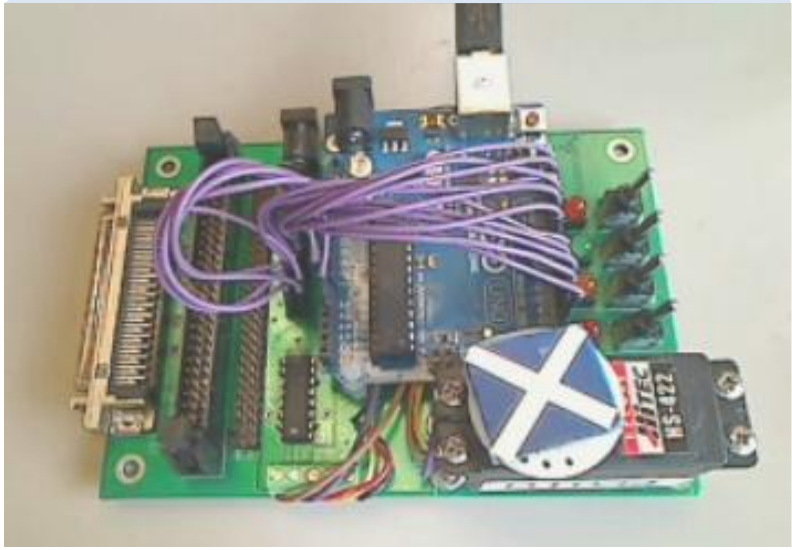
Des Angle

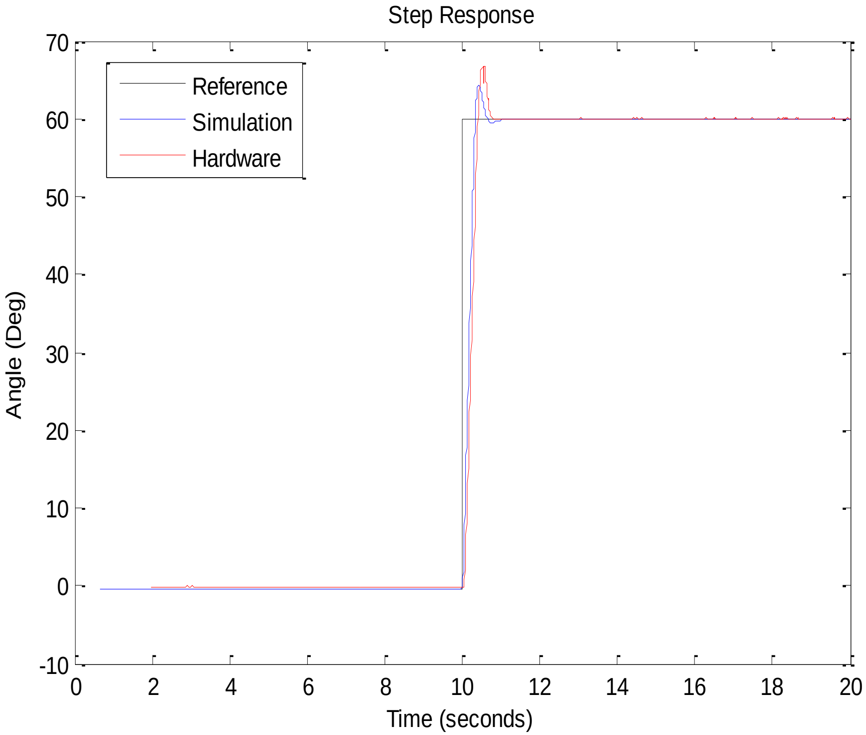
Act Angle

Closed Loop Interface

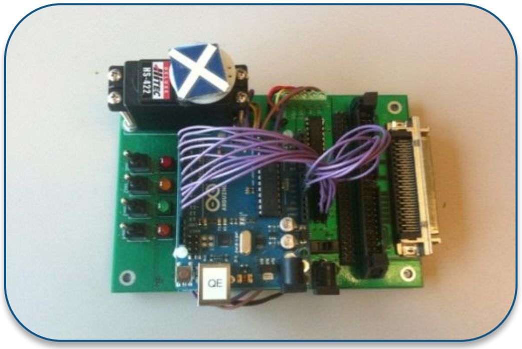
Actual Angle

Scope

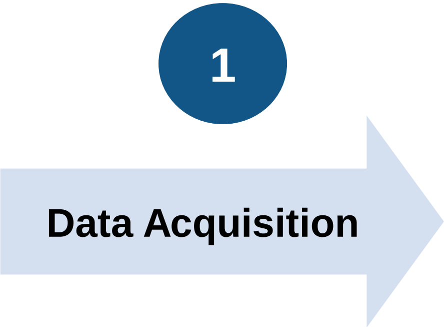




Workflow



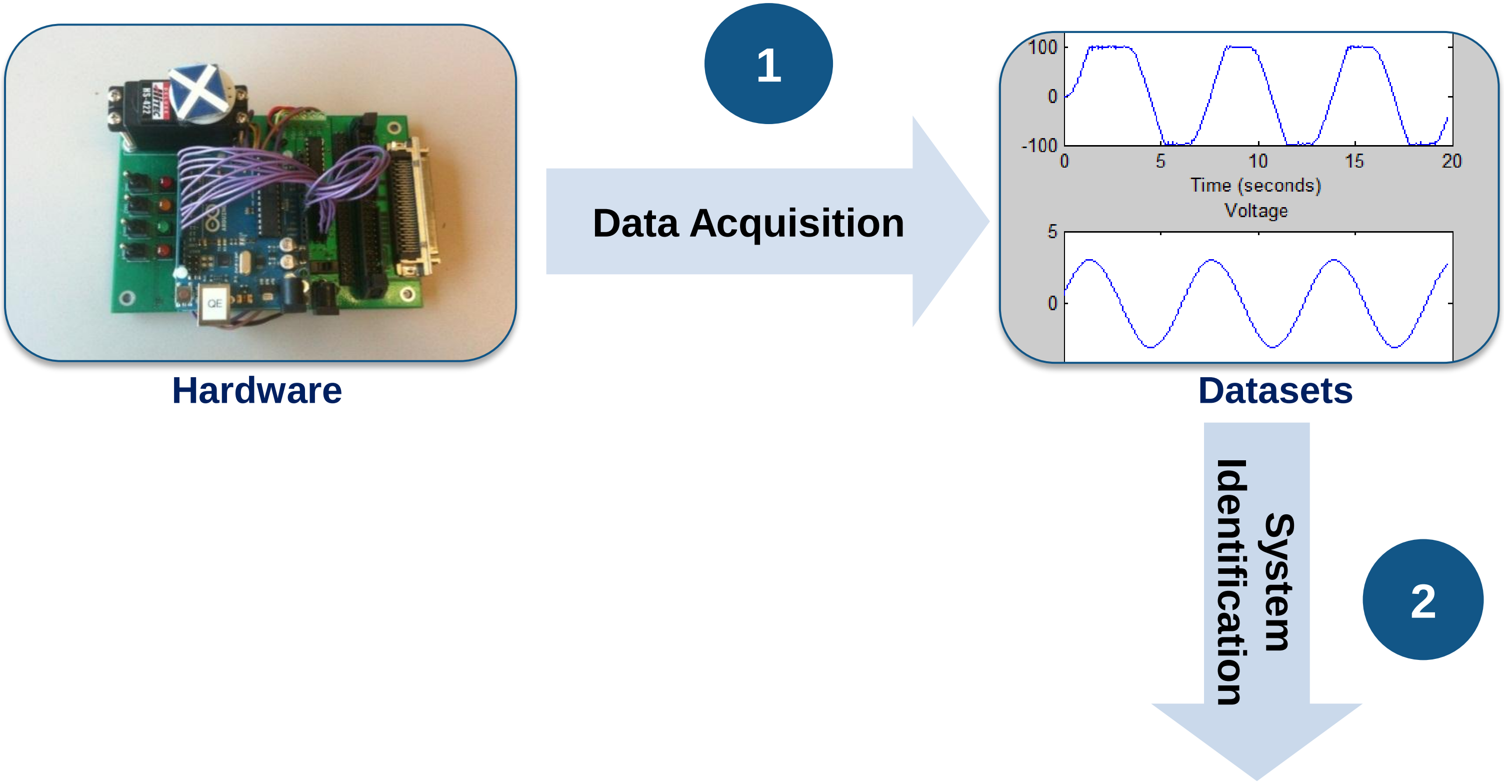
Hardware



1

Data Acquisition

Workflow



1

Data Acquisition

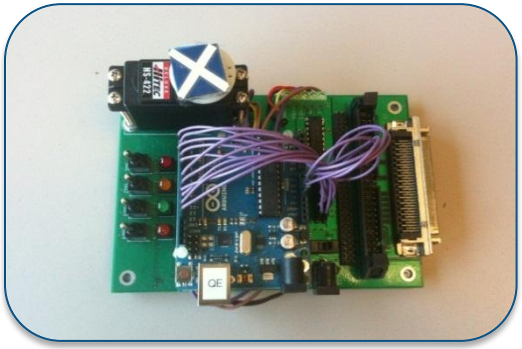
Hardware

Datasets

System Identification

2

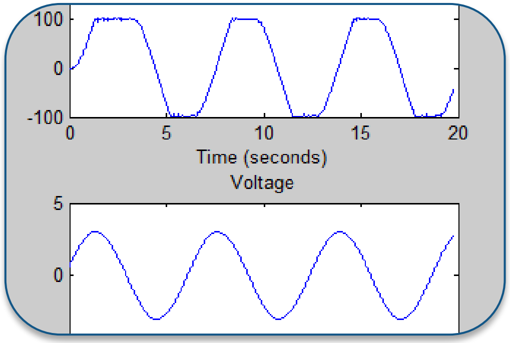
Workflow



Hardware

1

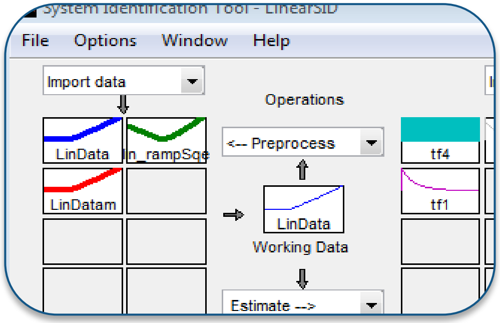
Data Acquisition



Datasets

System Identification

2

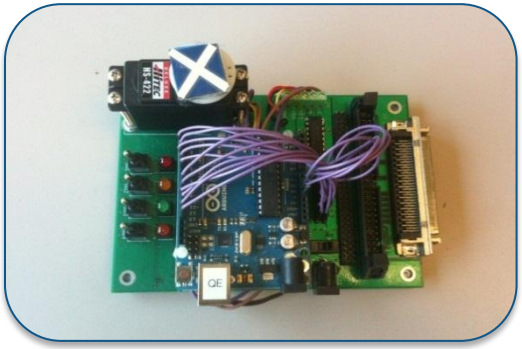


Plant Model

3

Controller Design

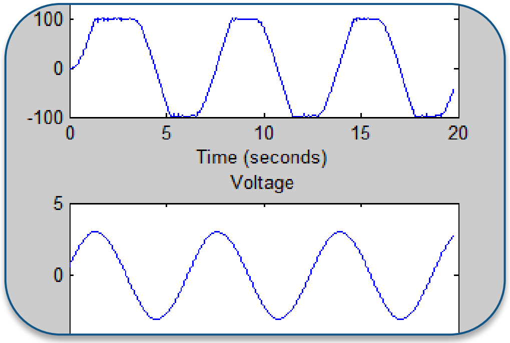
Workflow



Hardware

1

Data Acquisition



Datasets

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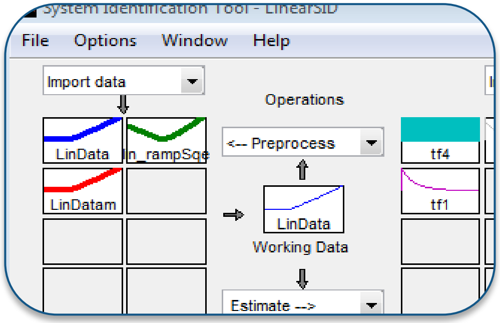
System Identification



Plant Model

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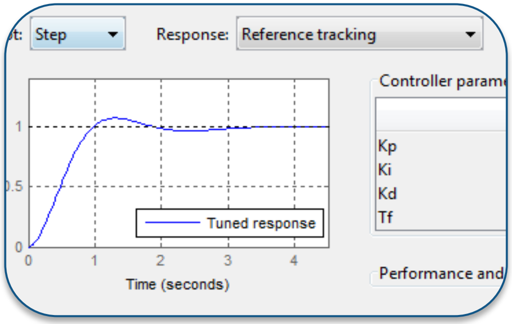
Controller Design



Control System

4

Real-Time Testing

Agenda

- Data Acquisition
  - Hardware setup
  - Run on Target Hardware

- System Identification
  - Linear model estimation
  - Nonlinear model estimation

- Controller Design
  - PID controller tuning
  - Desktop simulation with a nonlinear model

- Real-Time Testing and Controller Implementation
  - Deployment to Arduino Uno
  - Real-time controller evaluation

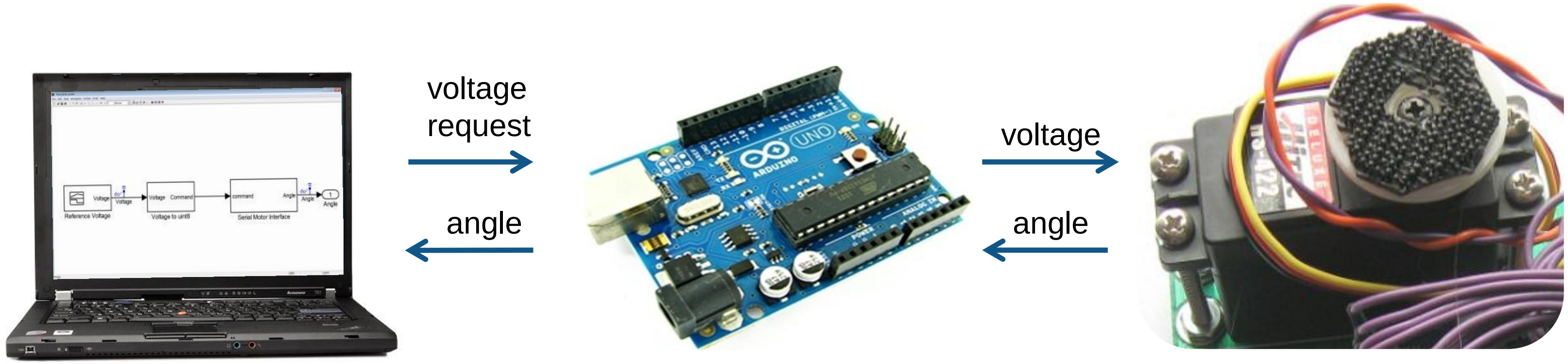
DATA ACQUISITION

Hardware Setup

Host Computer

Arduino Uno

DC Motor



voltage request

angle

voltage

angle

Serial communication

Motor driver

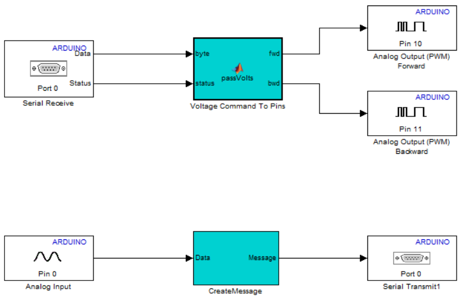
Run on Target Hardware

A Simulink feature in R2012a that:

- Creates an executable file from a model, and runs it on target hardware

- Is available from the model’s Tools menu
  - **Tools** > **Run on Target Hardware**

- Uses a *Target Installer* to install support packages for specific target hardware



ARDUINO UNO

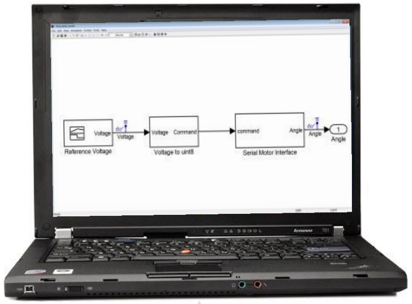
Requires Simulink®

Hardware Setup

Host Computer

Arduino Uno

DC Motor



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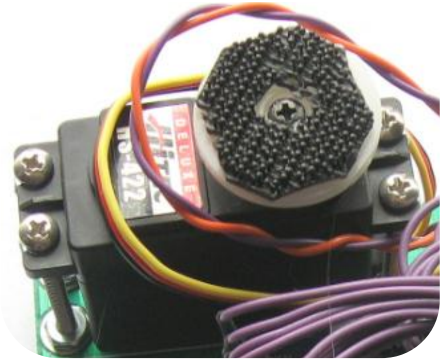
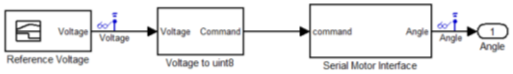
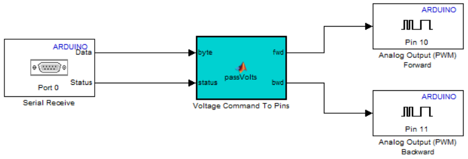
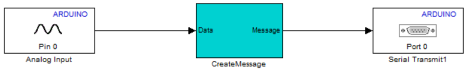


Serial communication (using Run On Target Hardware)

Motor driver

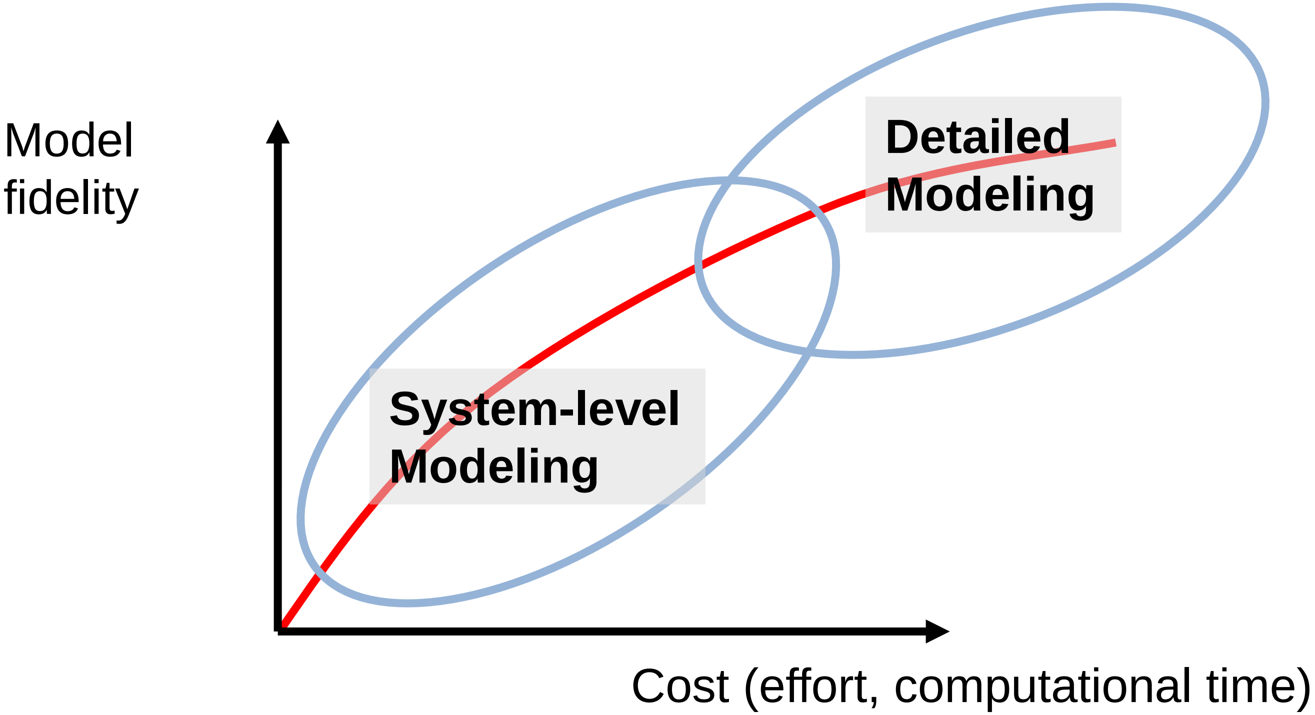






SYSTEM IDENTIFICATION

Model Fidelity vs. Cost



Model fidelity

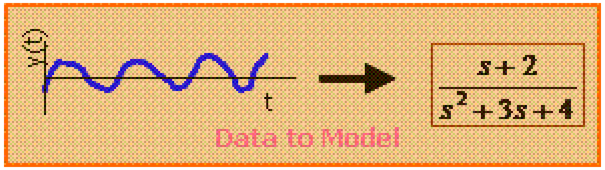
Detailed Modeling

System-level Modeling

Cost (effort, computational time)

- Model the dynamics that matter for your analysis
- Balance cost and model fidelity

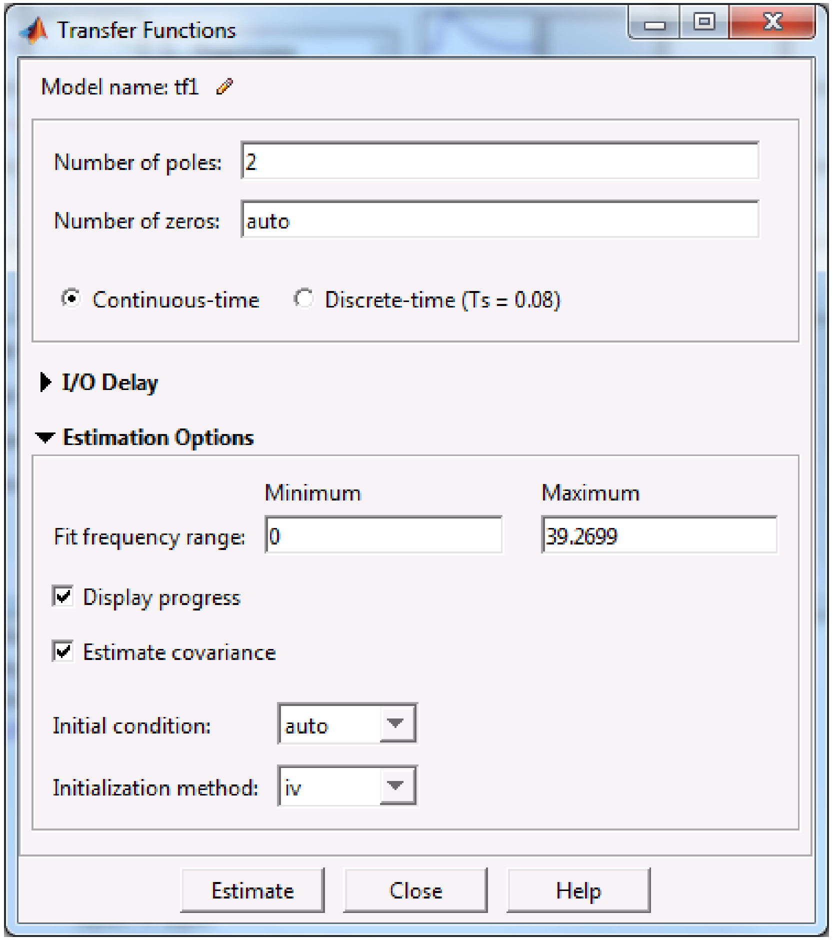
Linear System Identification



- Create continuous-time transfer functions from data

- Use either time or frequency domain data containing an arbitrary number of inputs and outputs

- Estimate other linear models: state-space, process models, and parametric models



Model name: tf1

Number of poles: 2

Number of zeros: auto

● Continuous-time ○ Discrete-time (Ts = 0.08)

	Minimum	Maximum
Fit frequency range:	0	39.2699

☑ Display progress

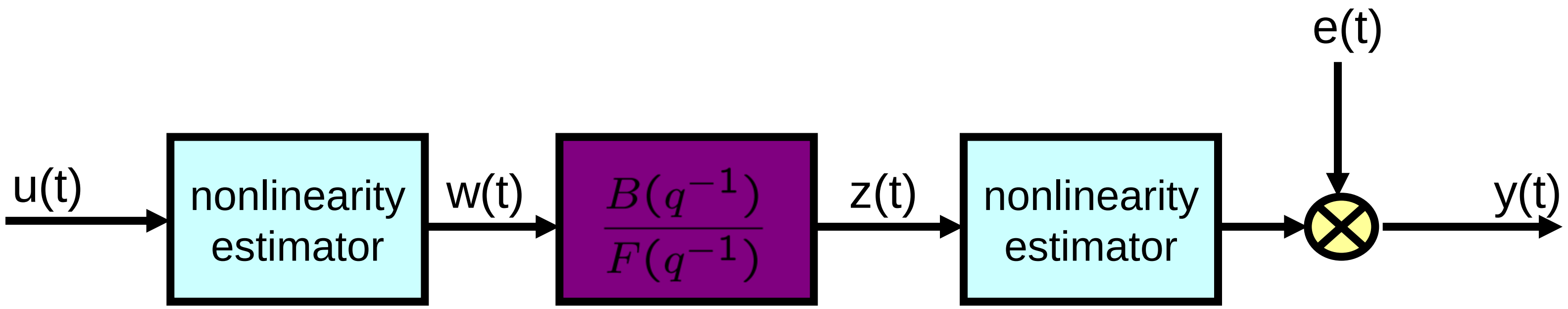
☑ Estimate covariance

Initial condition: auto

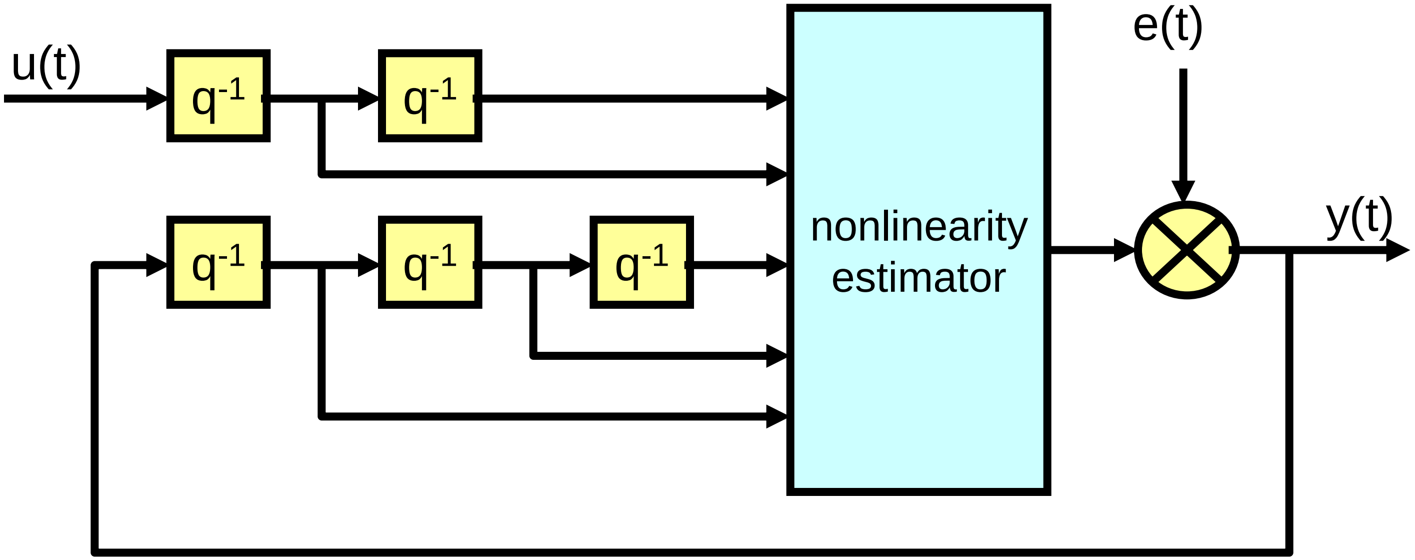
Initialization method: iv

Requires System Identification Toolbox™

Hammerstein-Wiener structure



Example of NLARX model



$$y(t) = f[y(t-1), y(t-2), y(t-3), u(t-1), u(t-2)] + e(t)$$

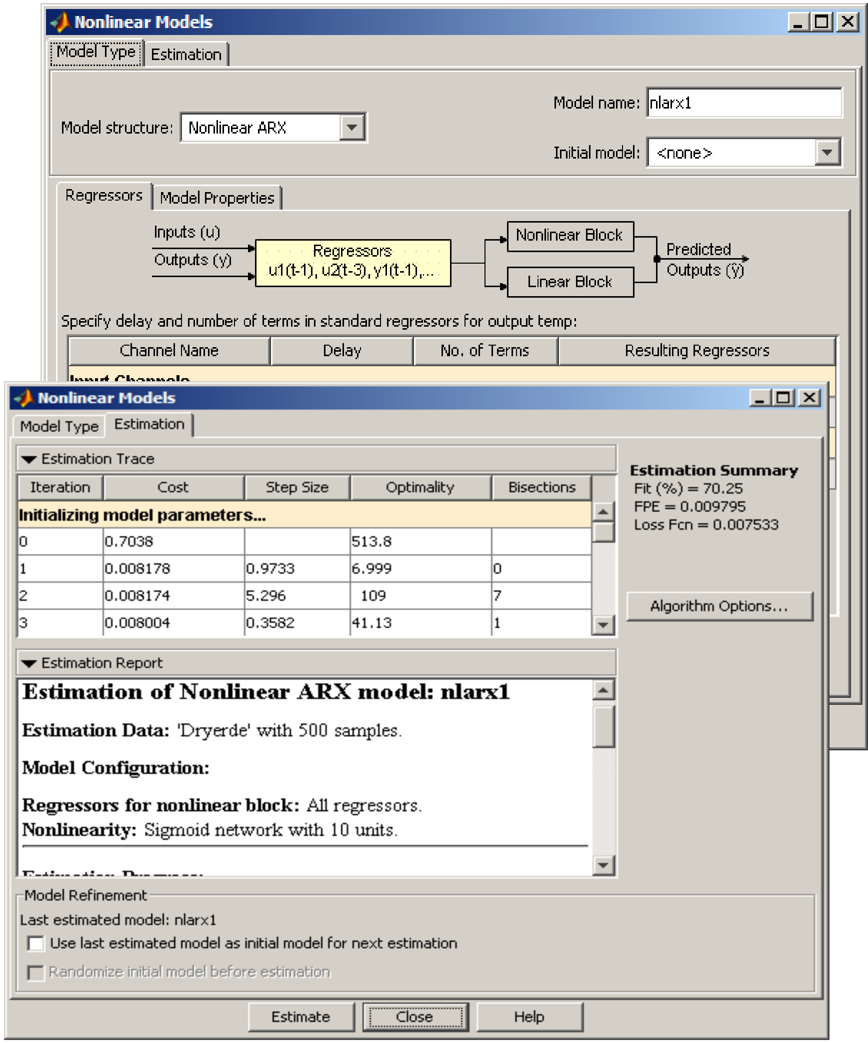
Nonlinear System Identification

- Estimate Hammerstein-Wiener models and nonlinear ARX models

- Use a variety of dynamic nonlinearities such as wavelets, neural networks, piecewise linear, etc.

- Estimate signal saturation and dead-zone behaviors affecting linear systems

- Use custom regressors in nonlinear ARX models for greater flexibility in modeling



Model structure: Nonlinear ARX

Model name: nlarx1

Initial model: <none>

Specify delay and number of terms in standard regressors for output temp:

Channel Name	Delay	No. of Terms	Resulting Regressors
Input Channels			

Iteration	Cost	Step Size	Optimality	Bisections
Initializing model parameters...				
0	0.7038		513.8	
1	0.008178	0.9733	6.999	0
2	0.008174	5.296	109	7
3	0.008004	0.3582	41.13	1

Estimation Summary
Fit (%) = 70.25
FPE = 0.009795
Loss Fcn = 0.007533

Estimation of Nonlinear ARX model: nlarx1

Estimation Data: 'Dryerde' with 500 samples.

Model Configuration:

Regressors for nonlinear block: All regressors.
Nonlinearity: Sigmoid network with 10 units.

Estimation Dynamics:

Model Refinement
Last estimated model: nlarx1
□ Use last estimated model as initial model for next estimation
□ Randomize initial model before estimation

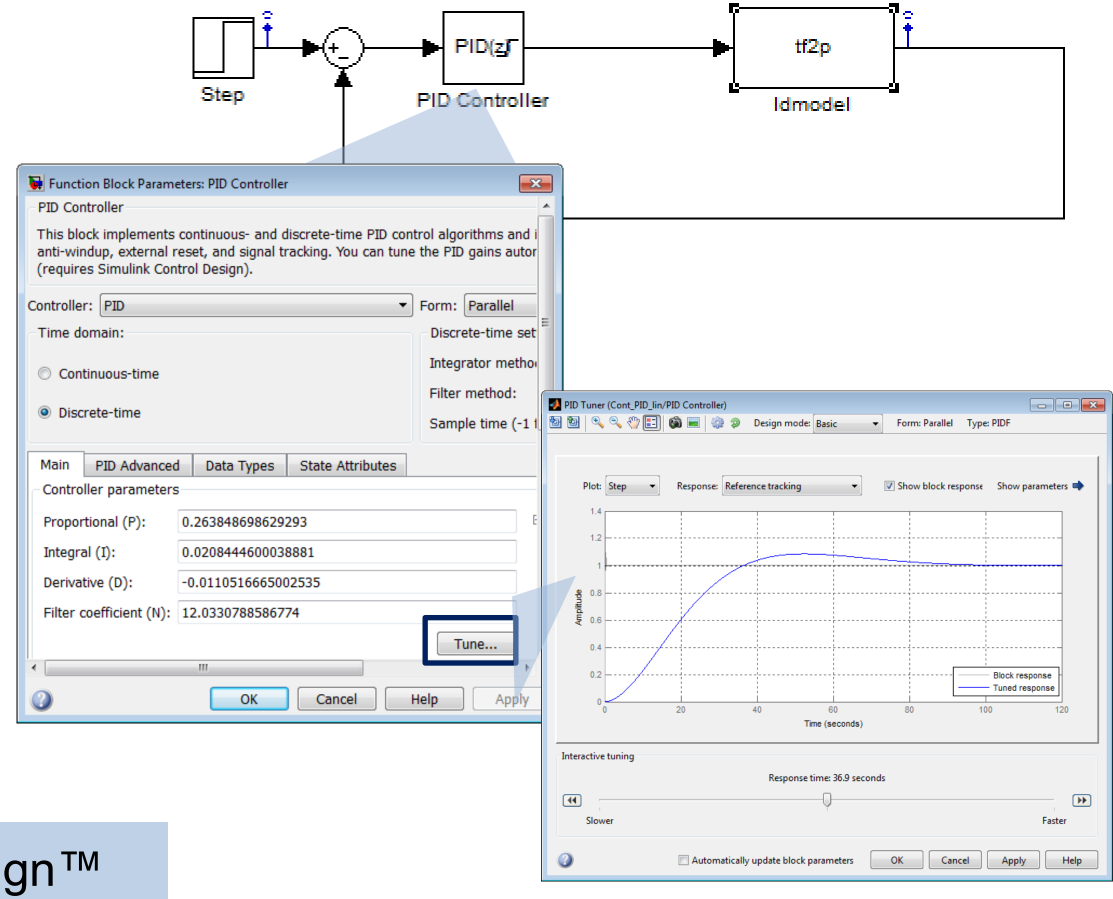
Requires System Identification Toolbox™

CONTROLLER DESIGN

Automatic PID Tuning

- Automatically linearizes Simulink models and finds gain values to meet specifications

- Provides additional fine-tuning capability with simple sliders



Function Block Parameters: PID Controller

PID Controller

This block implements continuous- and discrete-time PID control algorithms and i anti-windup, external reset, and signal tracking. You can tune the PID gains autor (requires Simulink Control Design).

Controller: PID
Form: Parallel

Time domain:
○ Continuous-time
● Discrete-time

Discrete-time set
Integrator metho
Filter method:
Sample time (-1 f

Controller parameters

Proportional (P):	0.263848698629293
Integral (I):	0.0208444600038881
Derivative (D):	-0.0110516665002535
Filter coefficient (N):	12.0330788586774

PID Tuner (Cont_PID_lin/PID Controller)

Design mode: Basic
Form: Parallel
Type: PIDF

Plot: Step
Response: Reference tracking
☑ Show block response
Show parameters

Interactive tuning

Response time: 36.9 seconds

☐ Automatically update block parameters

Requires Simulink Control Design™

For more info, watch our webinar “*PID Control Made Easy*”.

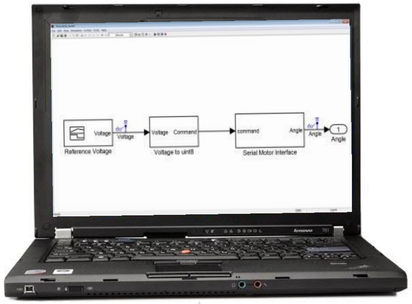
REAL-TIME TESTING AND CONTROLLER IMPLEMENTATION

Real-Time Testing

Host Computer

Arduino Uno

DC Motor

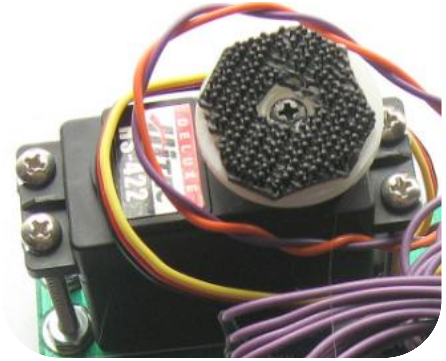


angle request

angle

voltage

angle



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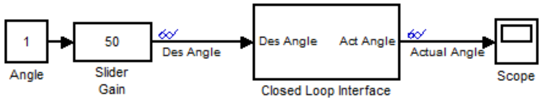
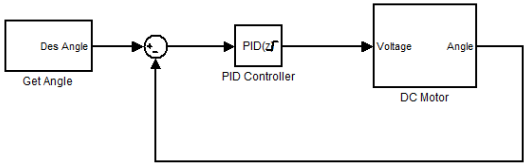
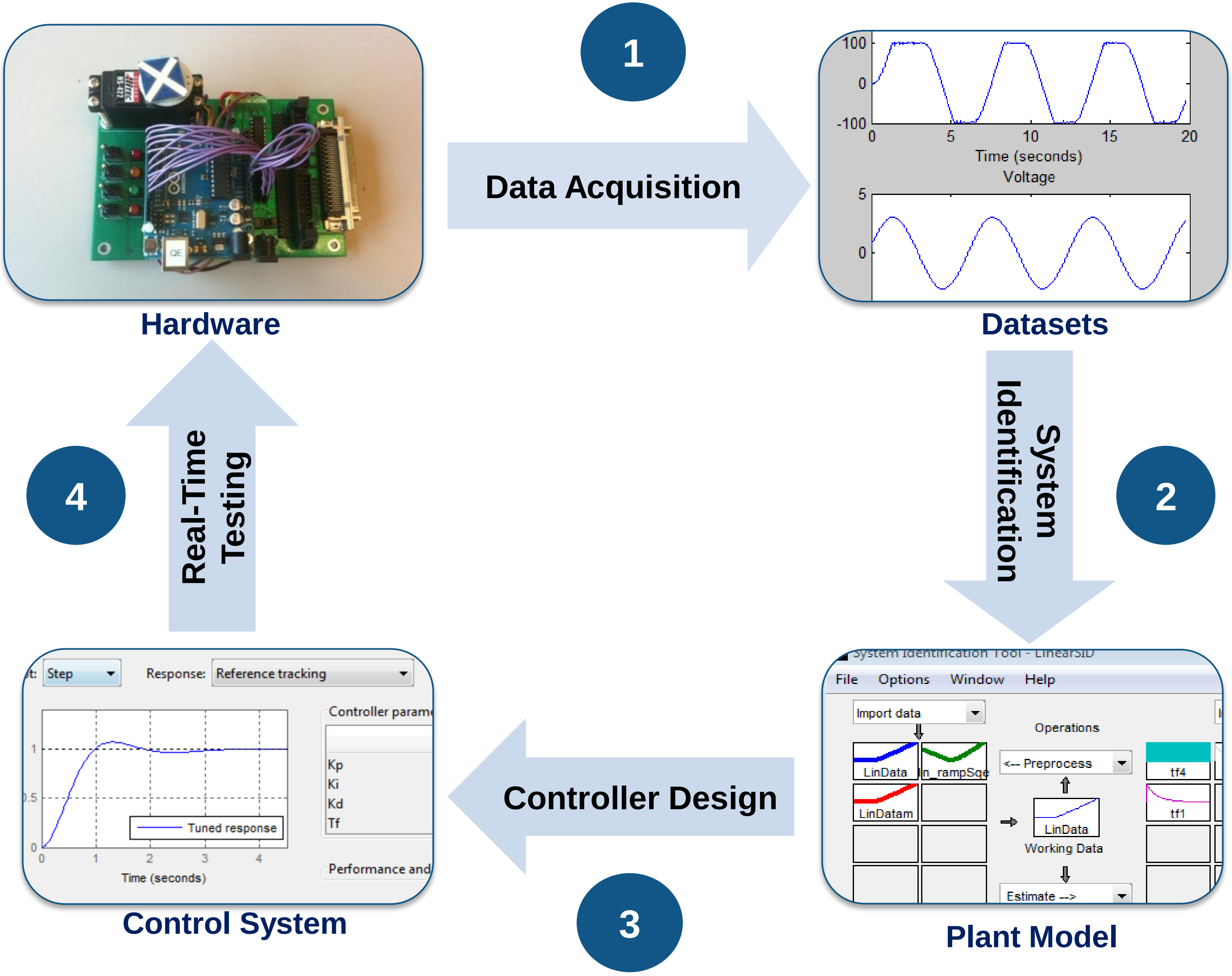




Workflow



1 Data Acquisition

Hardware

Datasets

2 System Identification

Plant Model

3 Controller Design

Control System

4 Real-Time Testing

Summary

- MATLAB and Simulink support data-driven control design

- MATLAB and Simulink provide an environment for
  - Data acquisition
  - System identification
  - Control design
  - Real-Time testing