# EE6104/EE5104 ADVANCED/ADAPTIVE CONTROL SYSTEMS

**Briefing Notes for CA3 Mini Project/ Sep ~~2009~~ 2018**

**Adaptive Control of Angular Position with Full State Measurable (EE6104 & EE5104)**
**and**
**Adaptive Control of Angular Velocity (EE6104 only)**
**being explored on the D.C. Motor**

**© Dr. K.Z.Tang, Mr. Lin Feng, Mr. Yang Chenguang & Prof. T.H.Lee**

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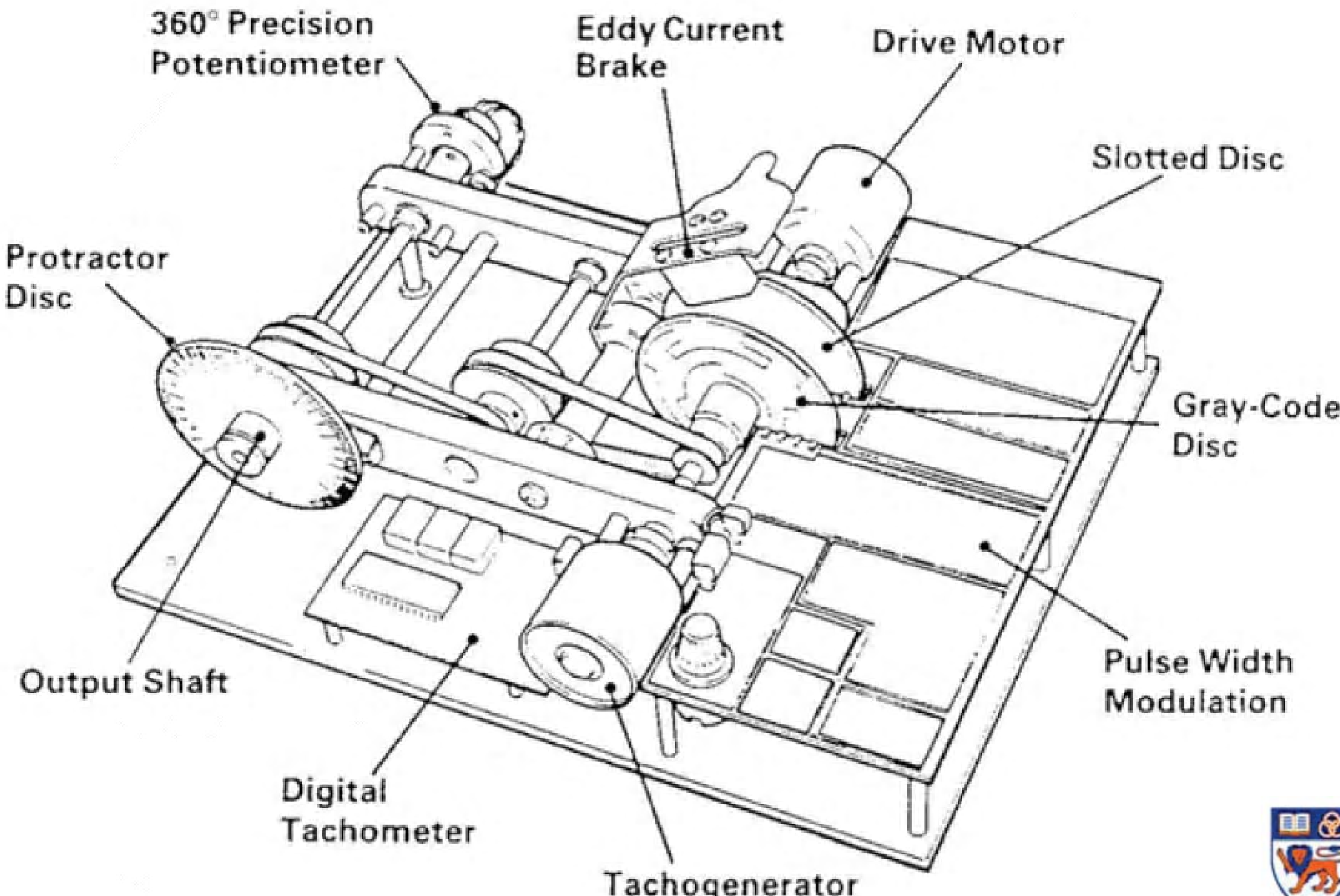
# Objectives

- The methods of adaptive control are used and explored on a pilot-scale hardware platform.
- A computer-aided design procedure is used to achieve the specifications, as part of the overall adaptive systems design.

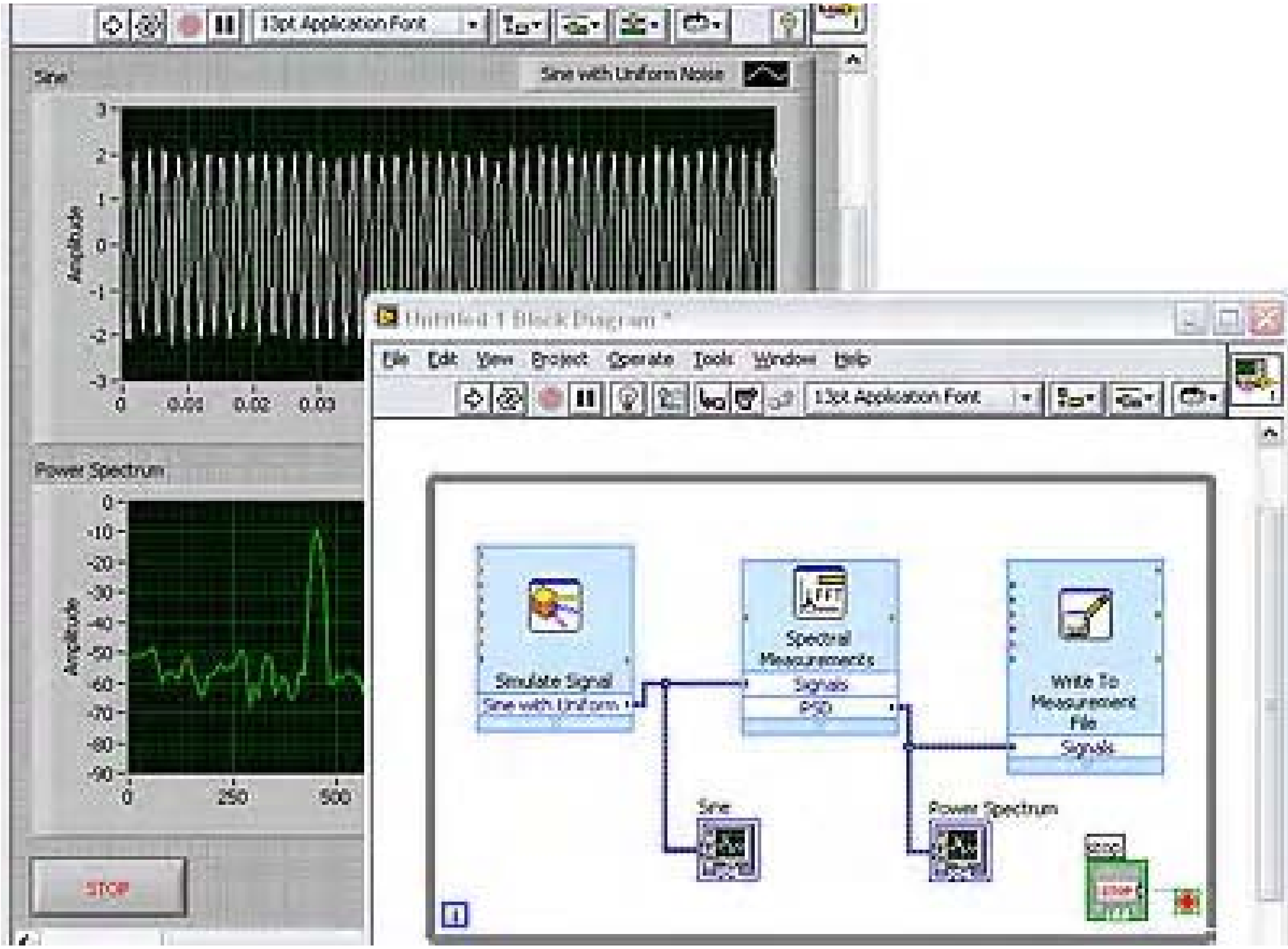
# Equipment

- PCs in the Control and Simulation Laboratory, E4A level 3, ECE Department
- L. J. Electronics D.C. motor apparatus
- PC-based data-acquisition system with a graphical icon-driven software
- National Instrument (NI) LabVIEW
- MATLAB software package

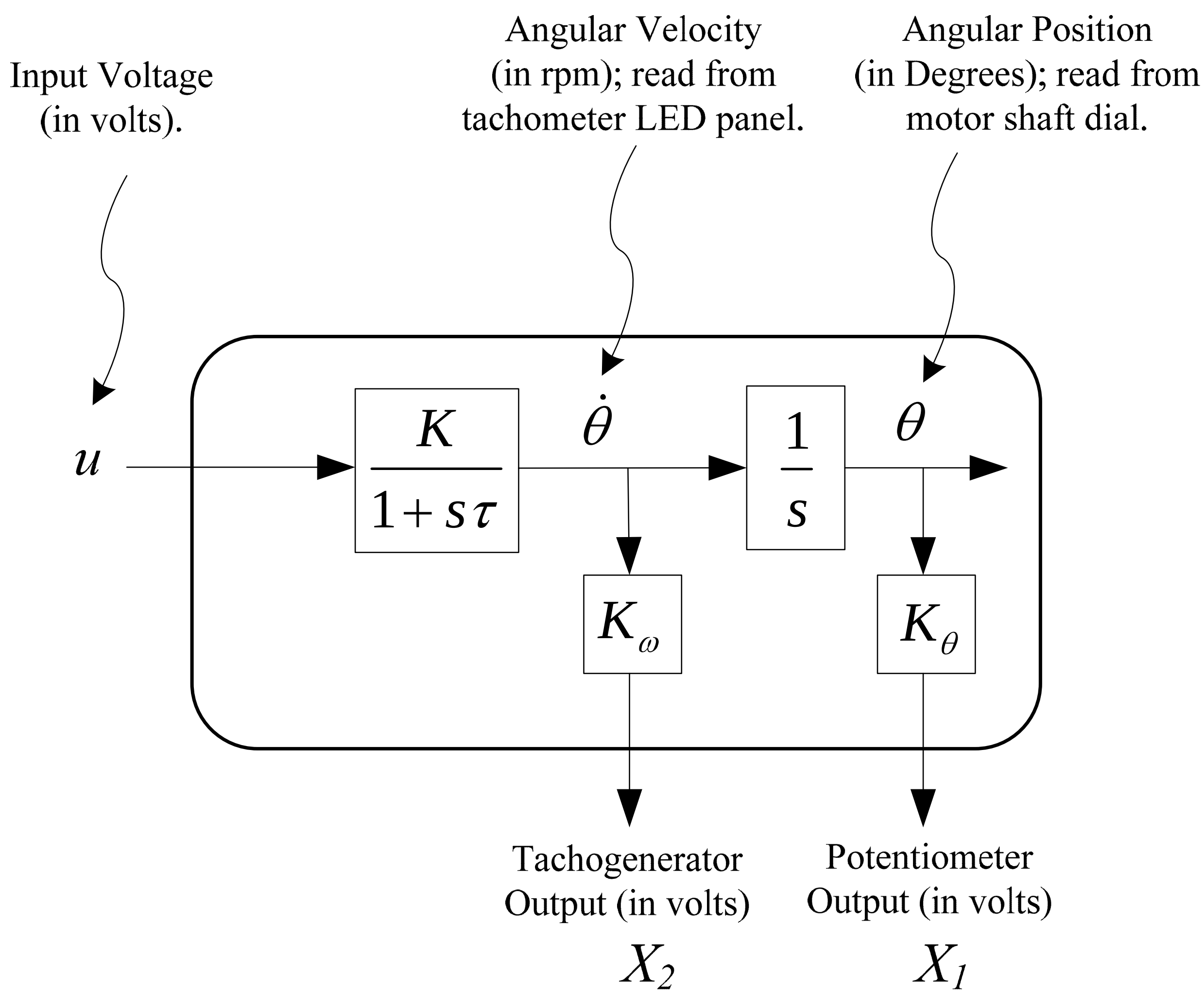
# D.C. Motor Apparatus



# Screenshot of LabVIEW



# Nominal Dynamic Model of Motor




Note that there is a 9:1 gear-down ratio from motor shaft to output shaft!!
Units with digital tacho on daughter board gives output shaft angular vel directly!!

# Breakdown of Project

1. Calibration of the D.C. motor sensors *(20 marks)*
2. Adaptive control of angular position with full state measurable; and additional original explorations *(EE6104: 60 marks; EE5104: 80 marks)*
3. Adaptive control of angular velocity; and additional original explorations *(for EE6104 students only! 20 marks)*

# 1. Calibration of the D.C. Motor Sensors

- D.C. motor has 2 types of sensors:
  - Potentiometer (angular position)
  - Tachometer (angular velocity)

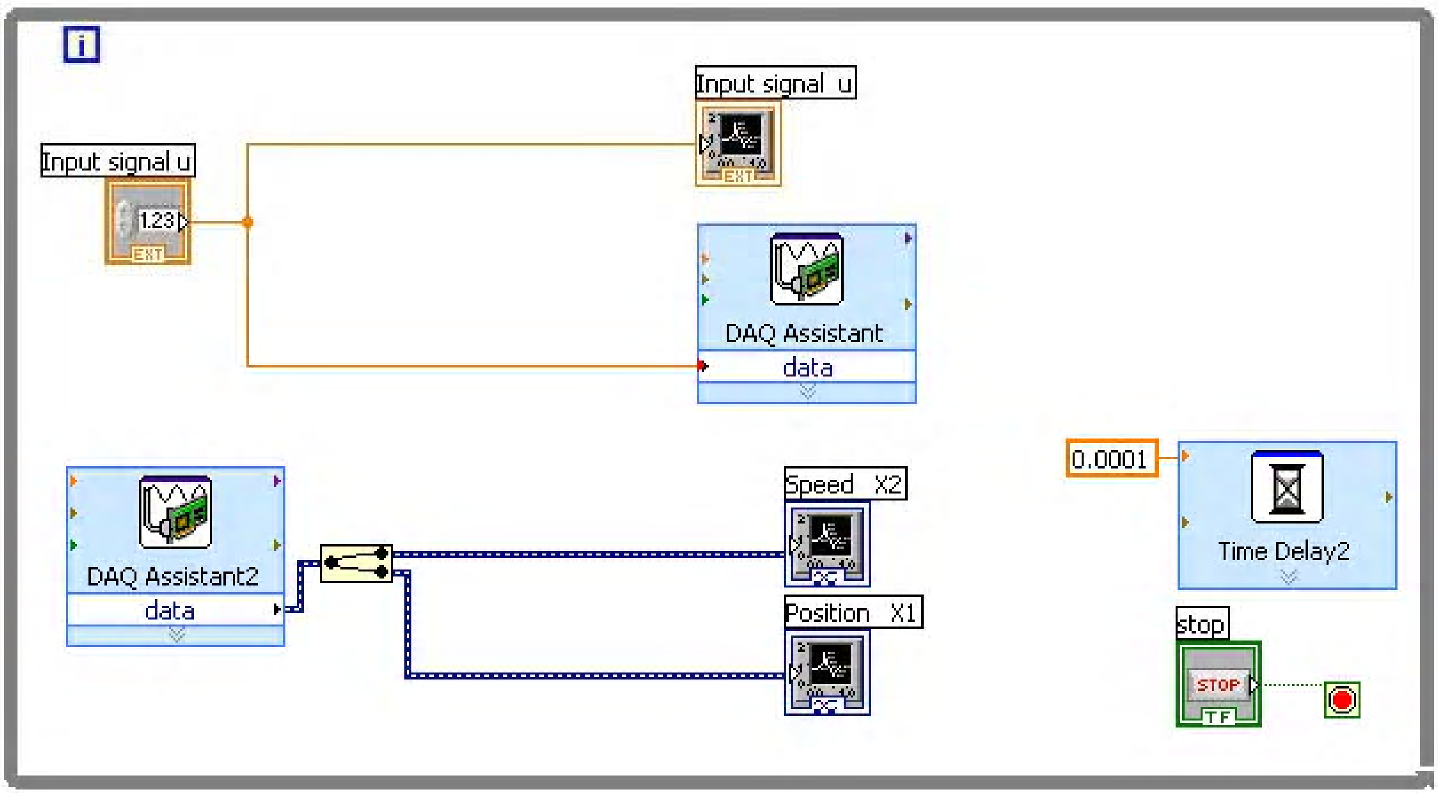
- Voltage outputs of the sensors need to be calibrated to the actual angular position and angular velocity measurements.

# 1. Calibration of the D.C. Motor Sensors

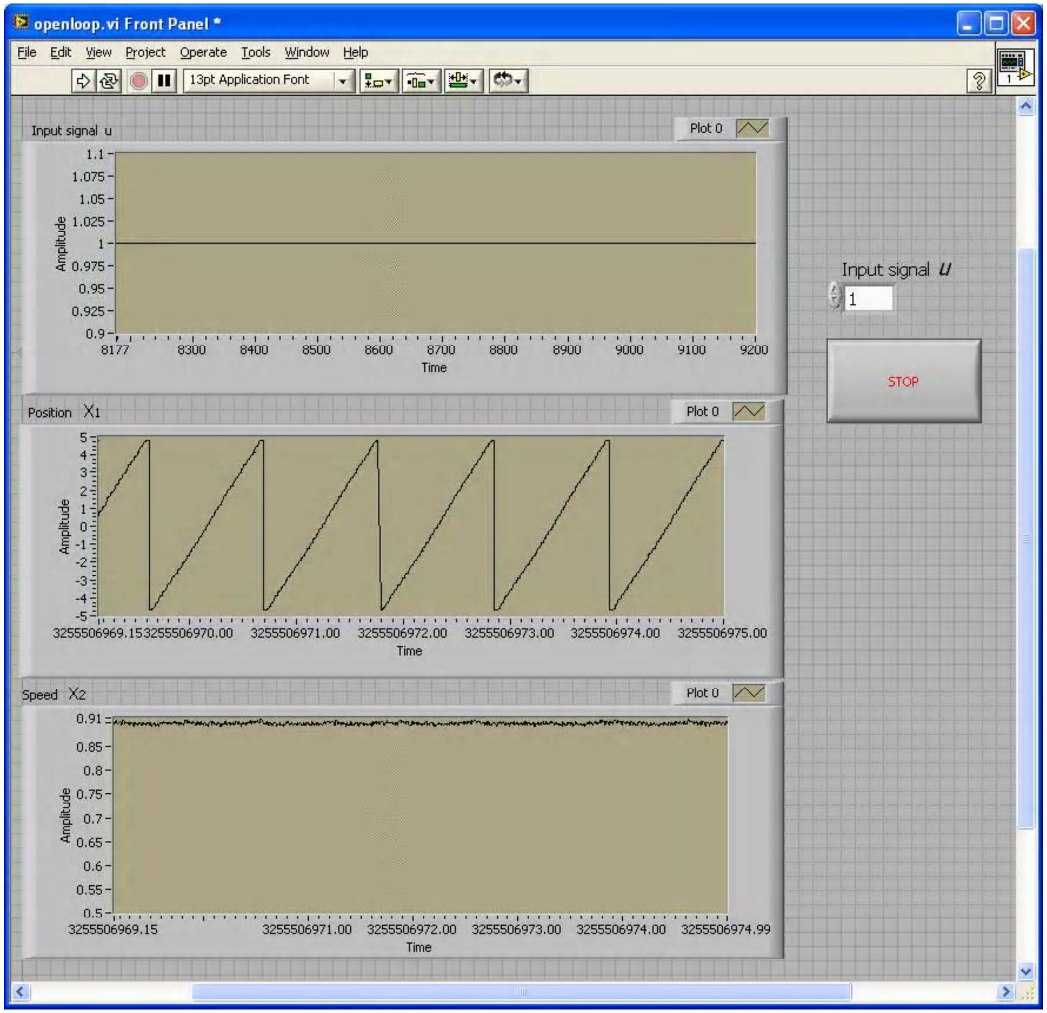
- Calibrate
  - voltage outputs of the sensors,
  - their relation to the actual angular position and angular velocity measurements.

- Show all your calibration data.
- Write down all pertinent notes and observations.

# LabVIEW Function Blocks used for Part 1



# Screen Capture for Part 1

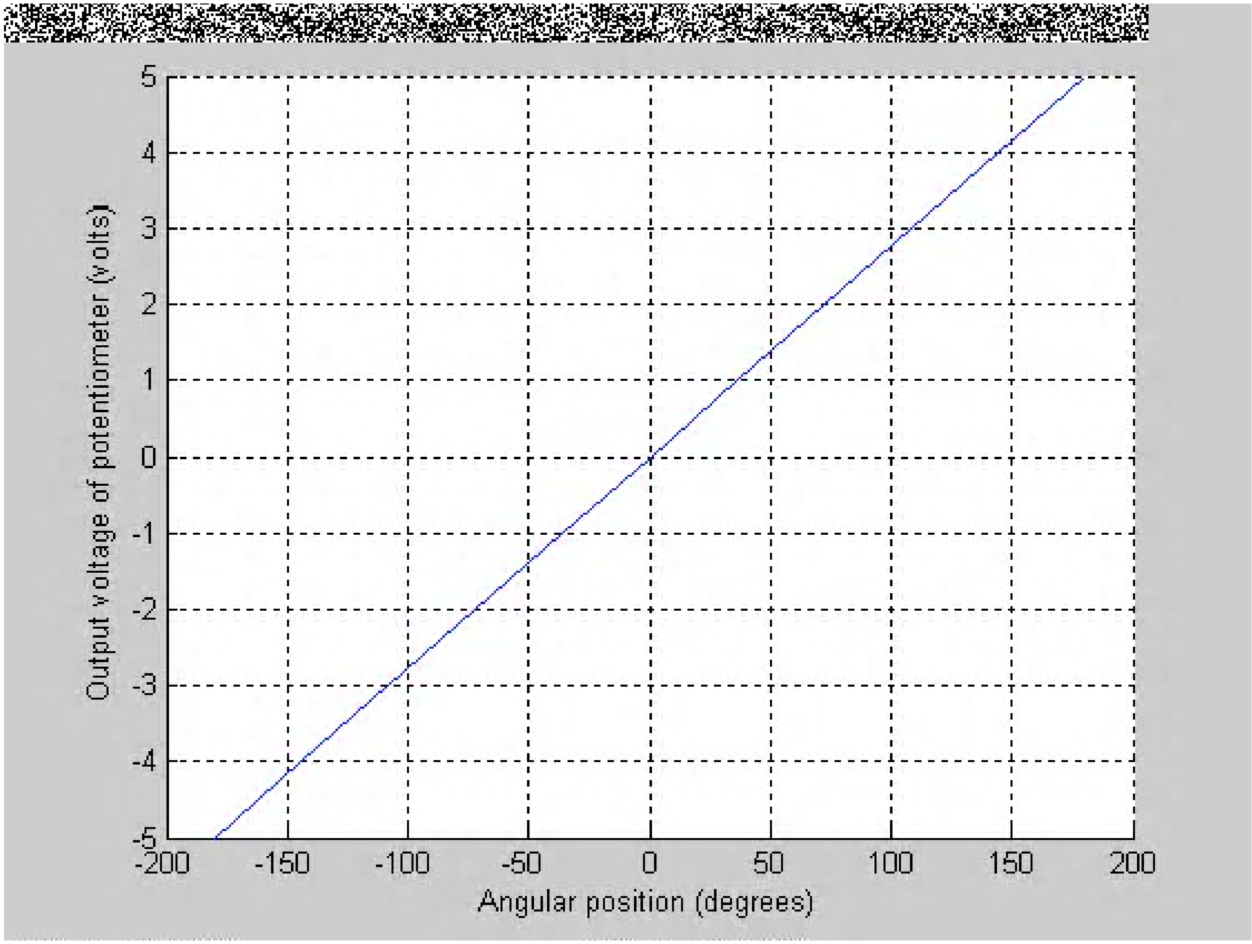


# Calibration Results for Part 1

| Potientiometer Output (in volts) | Angular Position (in degrees) |
|---|---|
| -5 | -180 |
| -4 | -144 |
| -3 | -108 |
| -2 | -72 |
| -1 | -36 |
| 0 | 0 |
| 1 | 36 |
| 2 | 72 |
| 3 | 108 |
| 4 | 144 |
| 5 | 180 |

Table 1 shows the results for the calibration of the potientiometer

# Calibration Results for Part 1



# Calibration Results for Part 1

| Input Voltage (volts) | Tachogenerator Output (volts) | Angular Velocity (rpm) | Angular Velocity (rad/sec) |
|---|---|---|---|
| -5 | -4.03 | -301 | -31.52 |
| -4 | -3.17 | -237 | -24.82 |
| -3 | -2.3 | -172 | -18.01 |
| -2 | -1.45 | -108 | -11.31 |
| -1 | -0.6 | -45 | -4.71 |
| 0 | 0 | 0 | 0 |
| 1 | 0.62 | 48 | 5.03 |
| 2 | 1.48 | 111 | 11.62 |
| 3 | 2.33 | 175 | 18.33 |
| 4 | 3.2 | 239 | 25.03 |
| 5 | 4.06 | 303 | 31.73 |

Table 2 shows the results for the calibration of the tachogenerator

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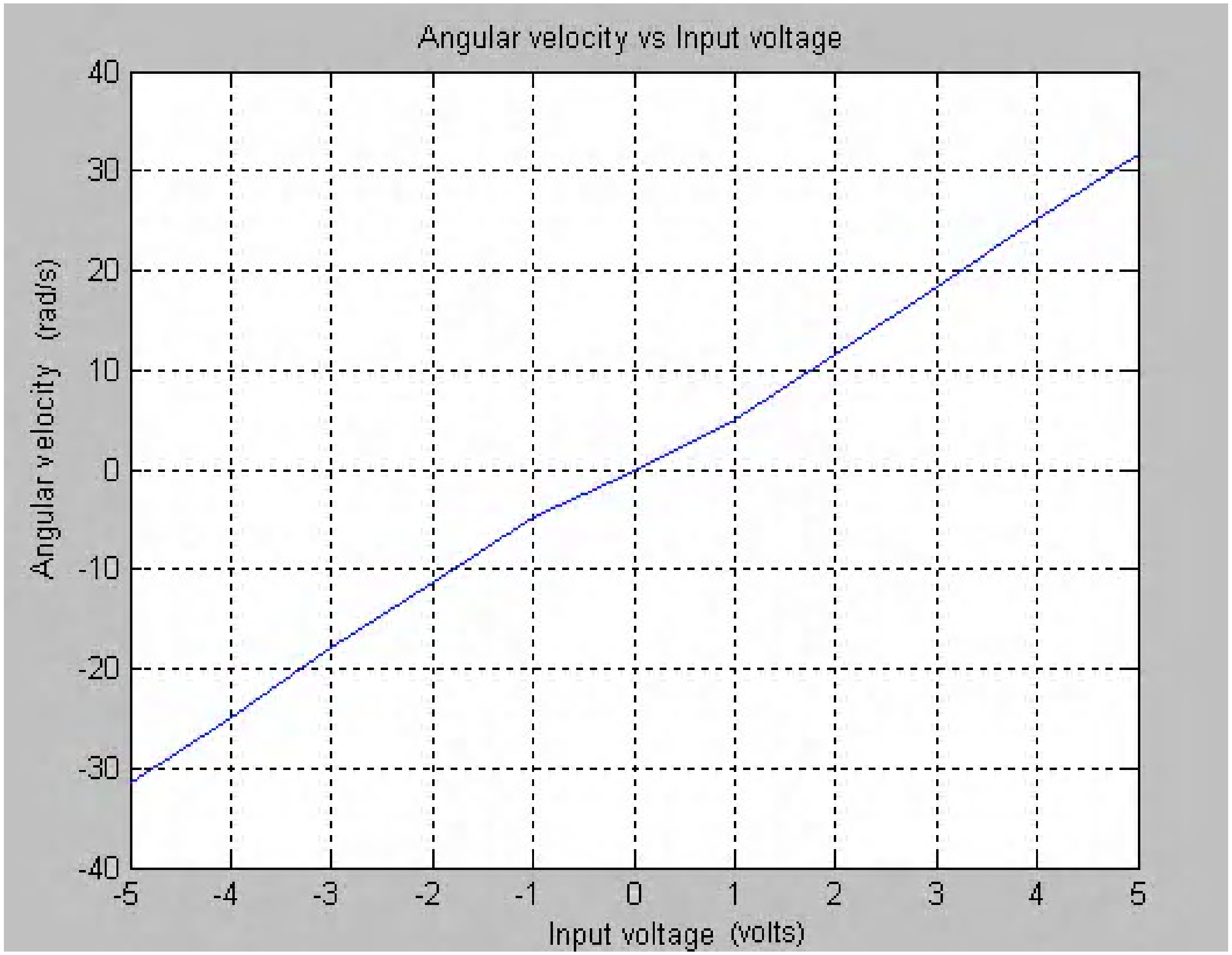
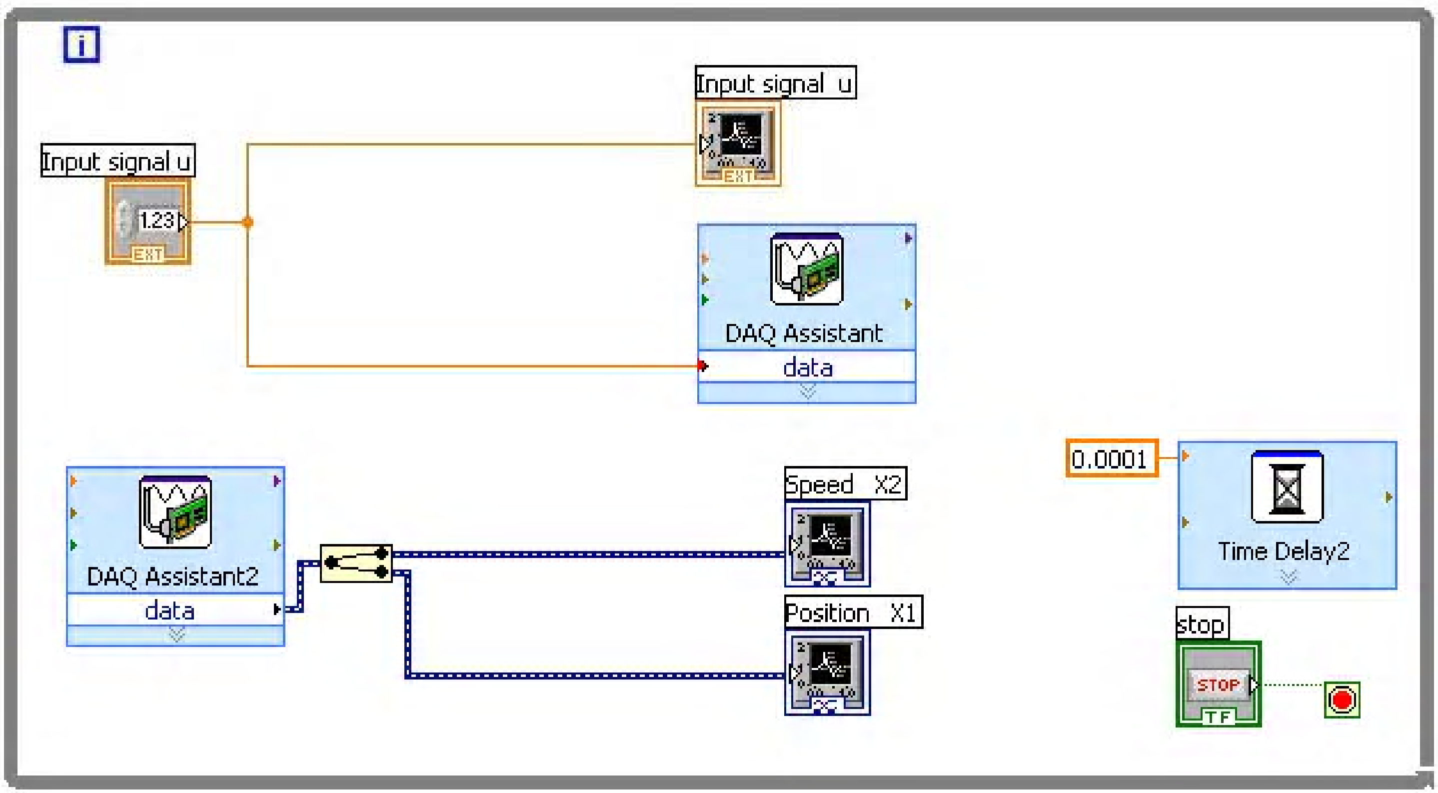
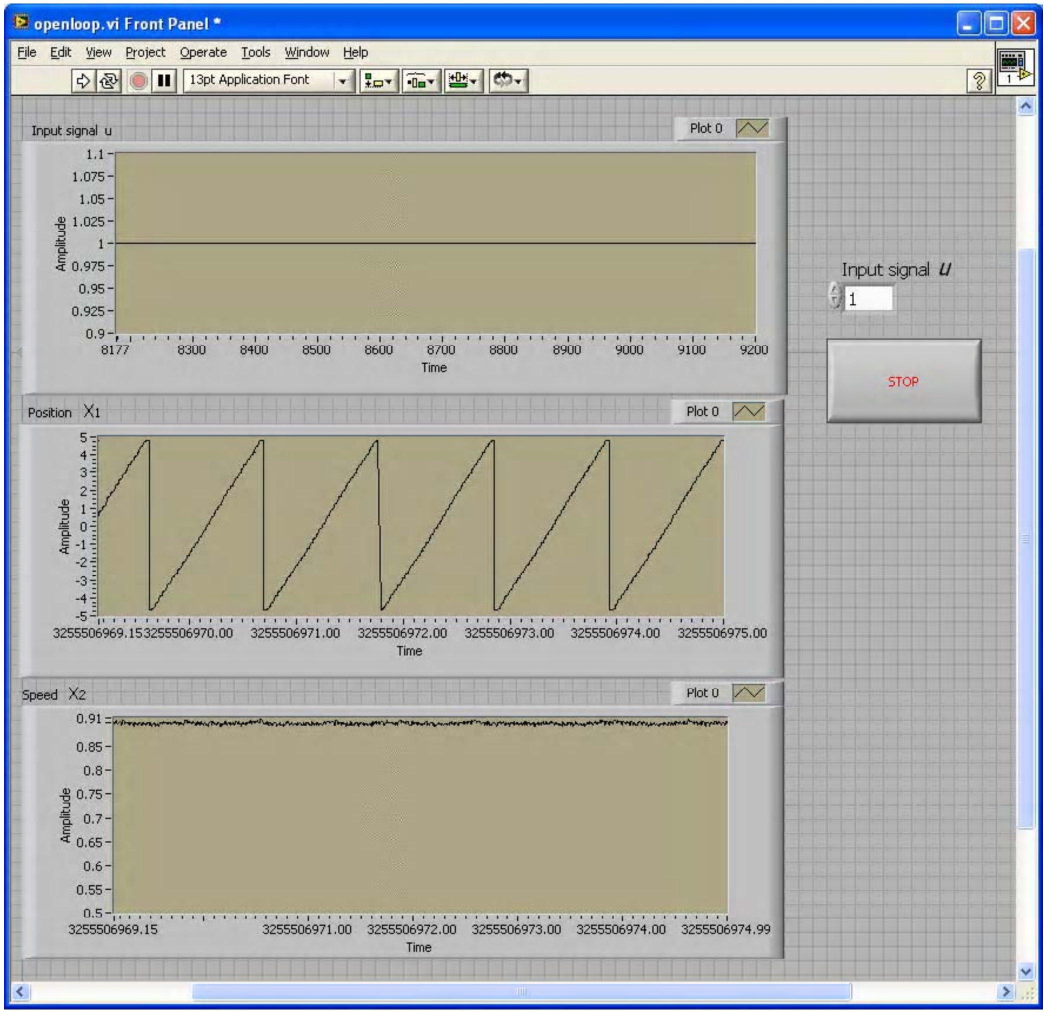
# Calibration Results for Part 1



# LabVIEW Function Blocks used for Part 1



# Screen Capture for Part 1



# 1. Calibration of the D.C. Motor Sensors

$\dot{\theta}$ = Angular velocity of motor shaft, read from digital tachometer

$\dot{\theta}_{motor}$ = Angular velocity of motor, obtained from voltage output of tachogenerator

$$\dot{\theta}_{motor} = 9\dot{\theta}$$

$\theta$ = Angular position of motor shaft, read from motor shaft dial

$\theta_{motor}$ = Angular position of motor, obtained from voltage output of potentiometer

$$\theta_{motor} = 9\theta$$

# 2. Adaptive Control of Angular Position with Full State Measurable

- Design and implement an adaptive controller with full state measurable for angular position control.
- For the controller, select suitable design choice(s) based on your results in the previous subsection.
- Using the NI LabVIEW system, investigate & explore various design choices of your adaptive controller for a suitably chosen position reference signal.
- Further investigate all signals/variables of suitable interest, and discuss!!! (Sep 2009; to note further.)

# 2. Adaptive Control of Angular Position with Full State Measurable

- Plant

$$\dot{x}_p = A_p x_p + gbu$$

where $x_p \in \Re^2$ is measurable and *b* is known

- Control Law

$$u(t) = \vartheta_x^T(t) x_p(t) + \vartheta_r(t) r(t)$$

# 2. Adaptive Control of Angular Position with Full State Measurable

- Adaptive Law

$$e = x_p - x_m$$

$$A_m^T P + P A_m = -Q$$

Choose *Q* and calculate *P*

$$\begin{bmatrix} \dot{\vartheta}_x \\ \dot{\vartheta}_r \end{bmatrix} = -\mathrm{sgn}(g)\Gamma \begin{bmatrix} x_p \\ r \end{bmatrix} e^T P b$$

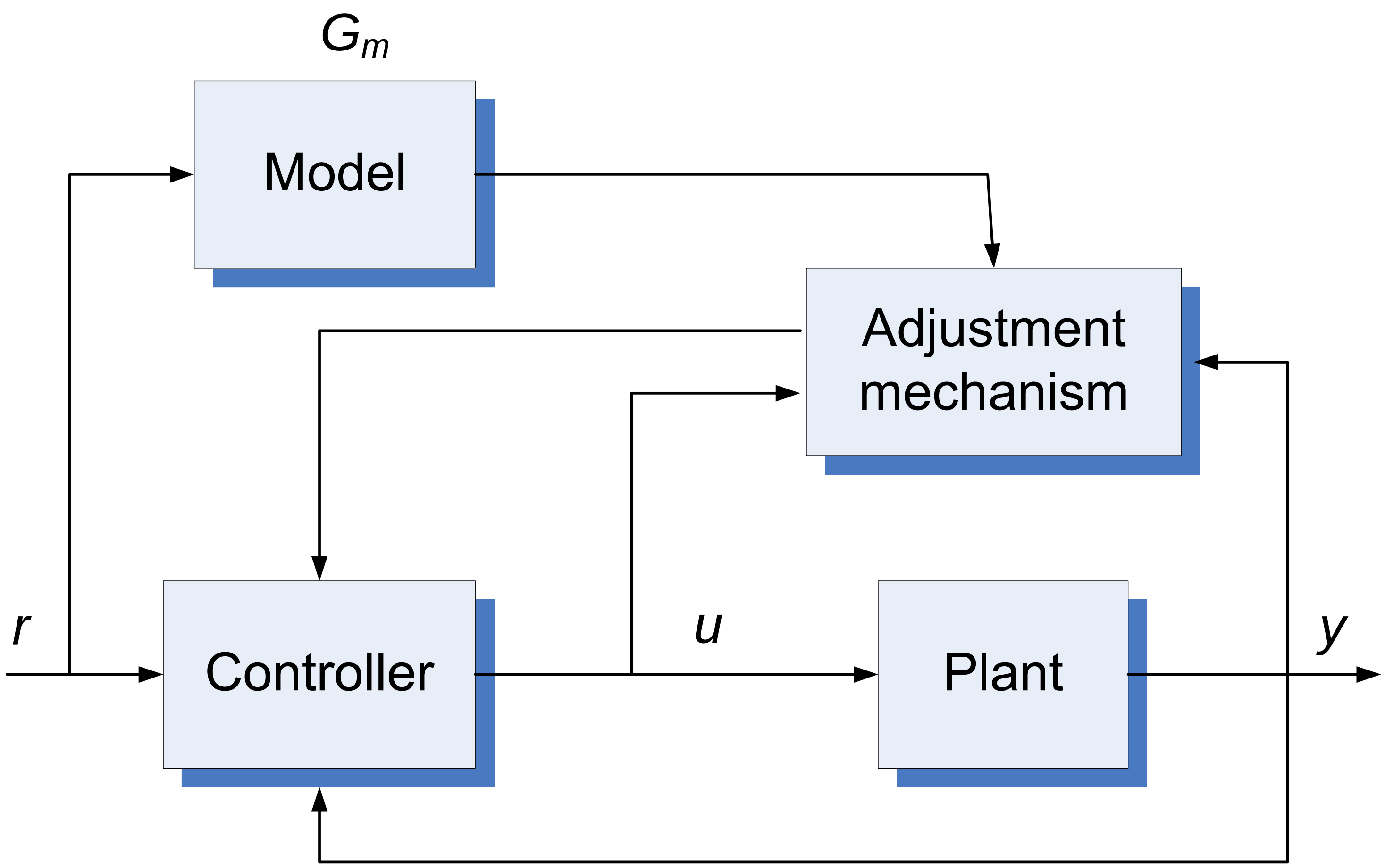
# 2. Adaptive Control of Angular Position with Full State Measurable

Note that proper design ensures that

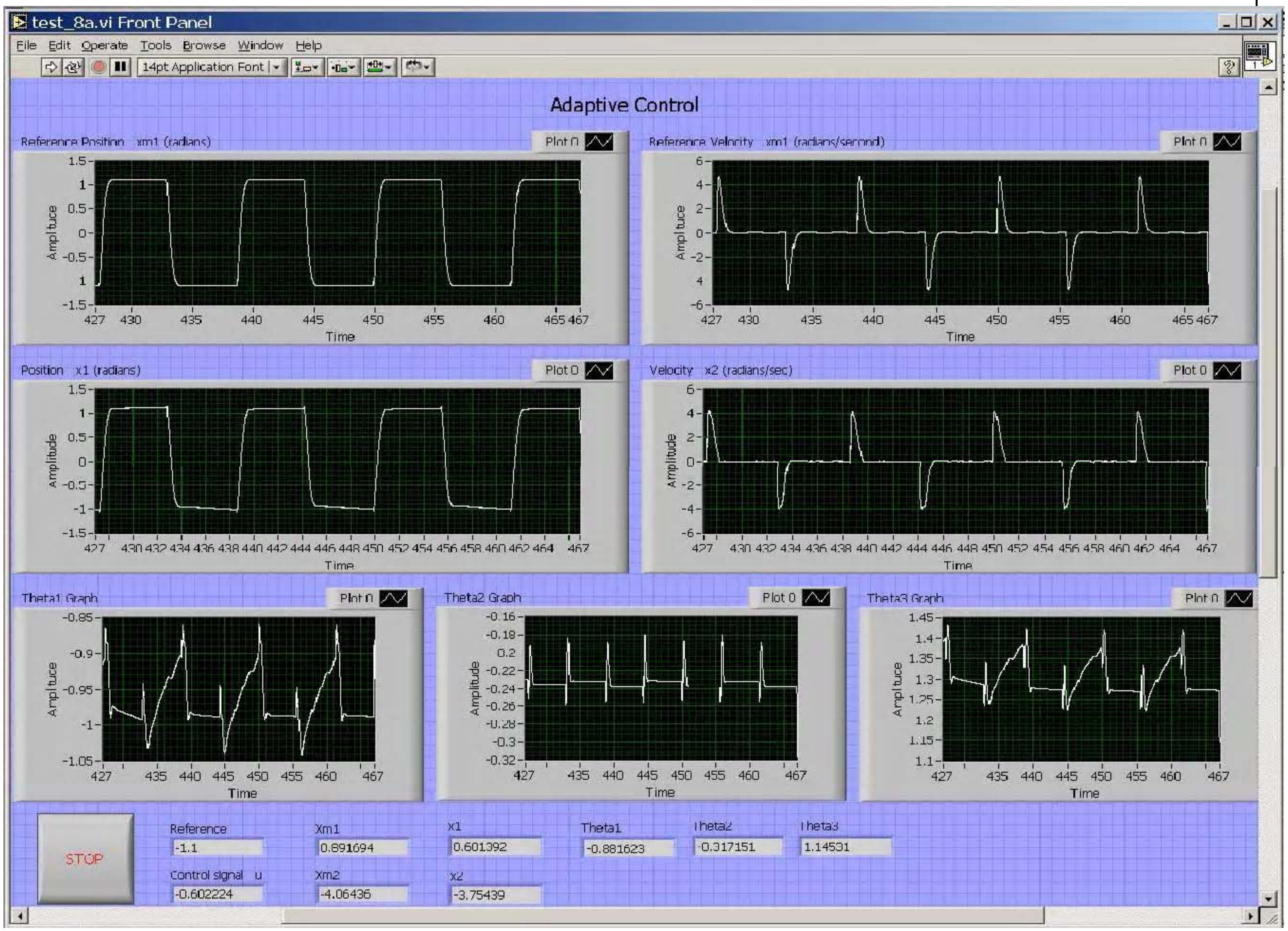
$$\left\{ \vartheta_x \ , \quad x_p \ , \quad \vartheta_r \right\}$$ are bounded, and

$$\lim_{t \to \infty} \left\| x_p - x_m \right\| = 0$$

# 2. Adaptive Control of Angular Position with Full State Measurable



# 2. Adaptive Control of Angular Position with Full State Measurable



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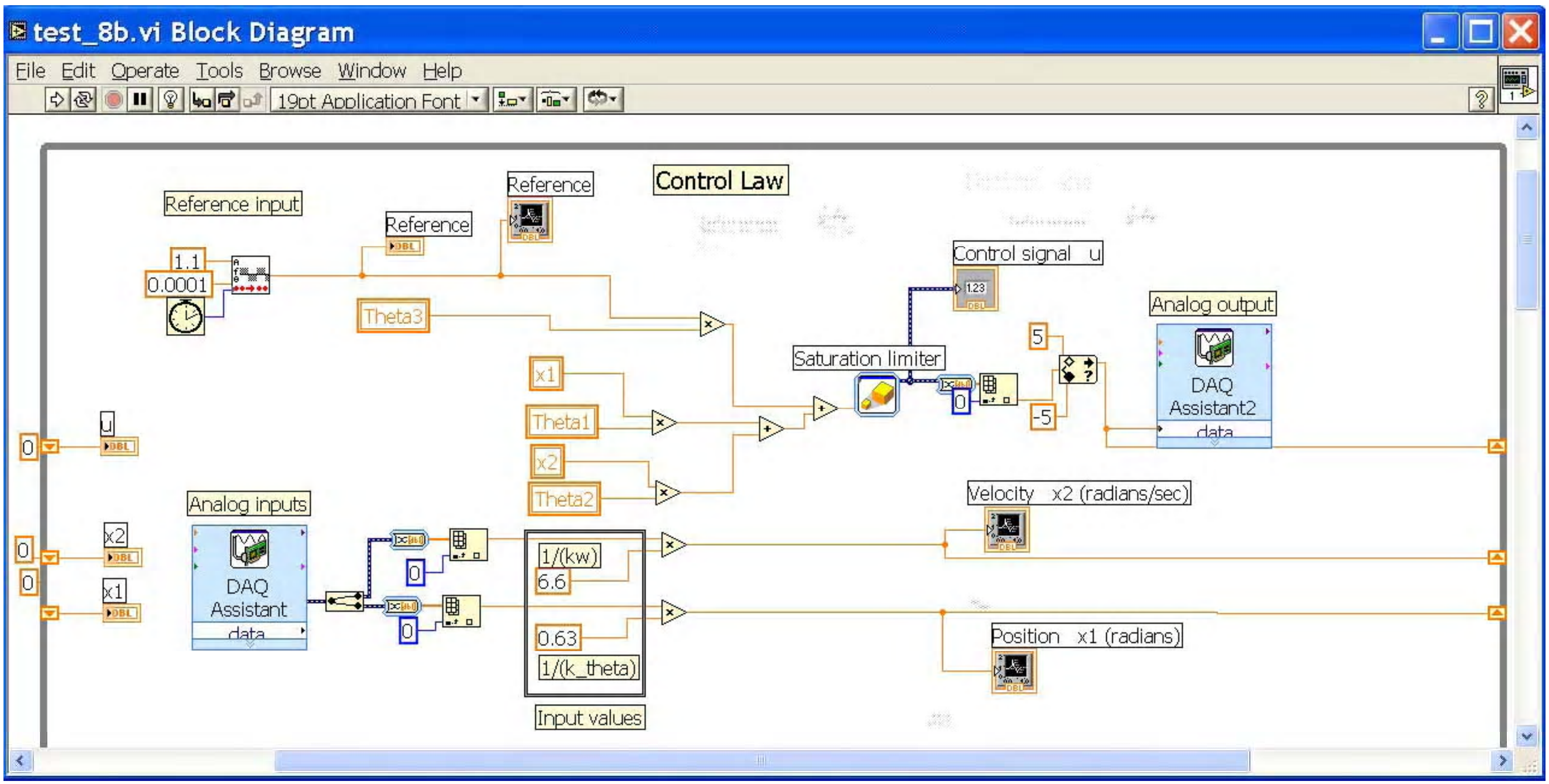

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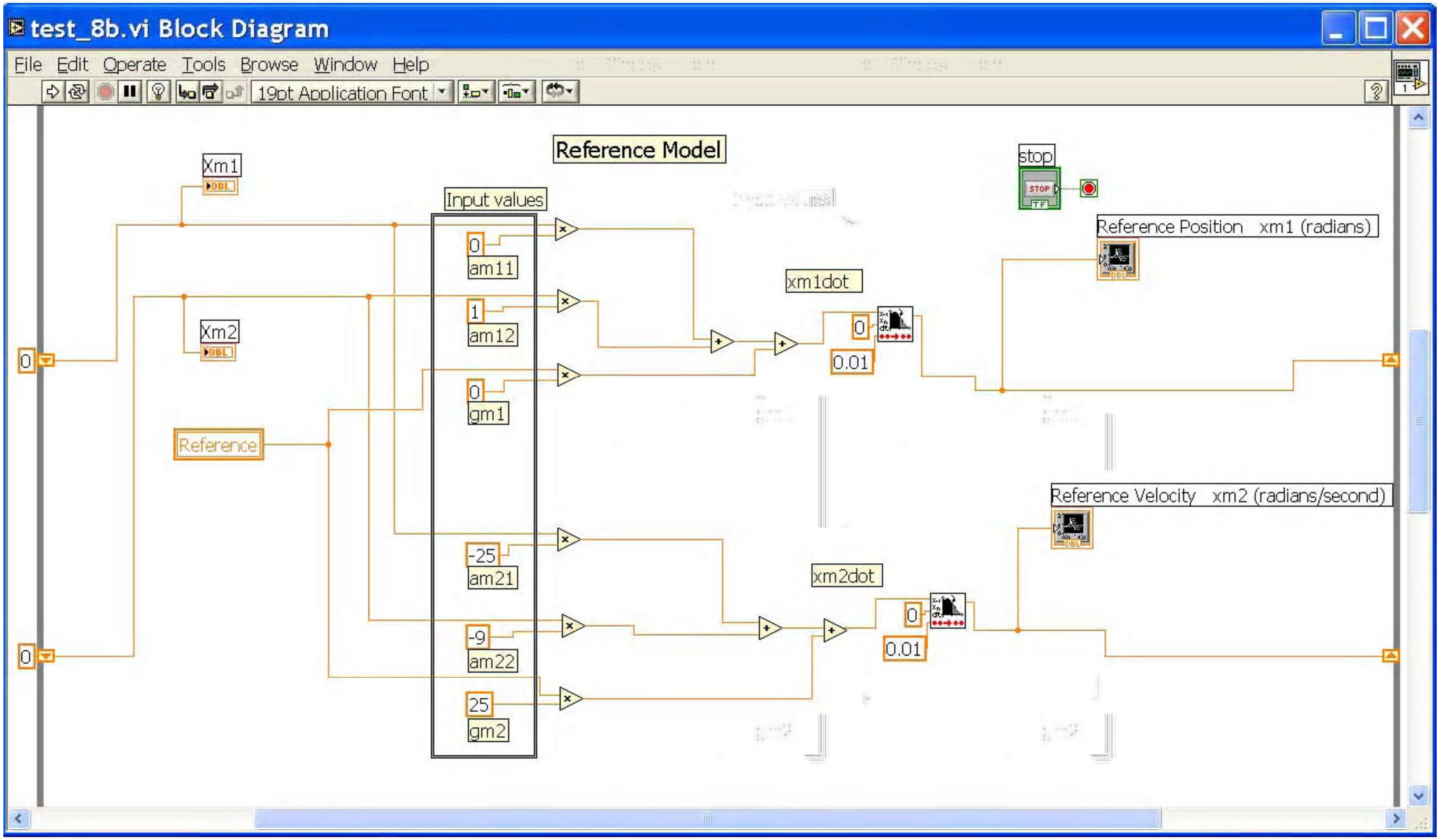
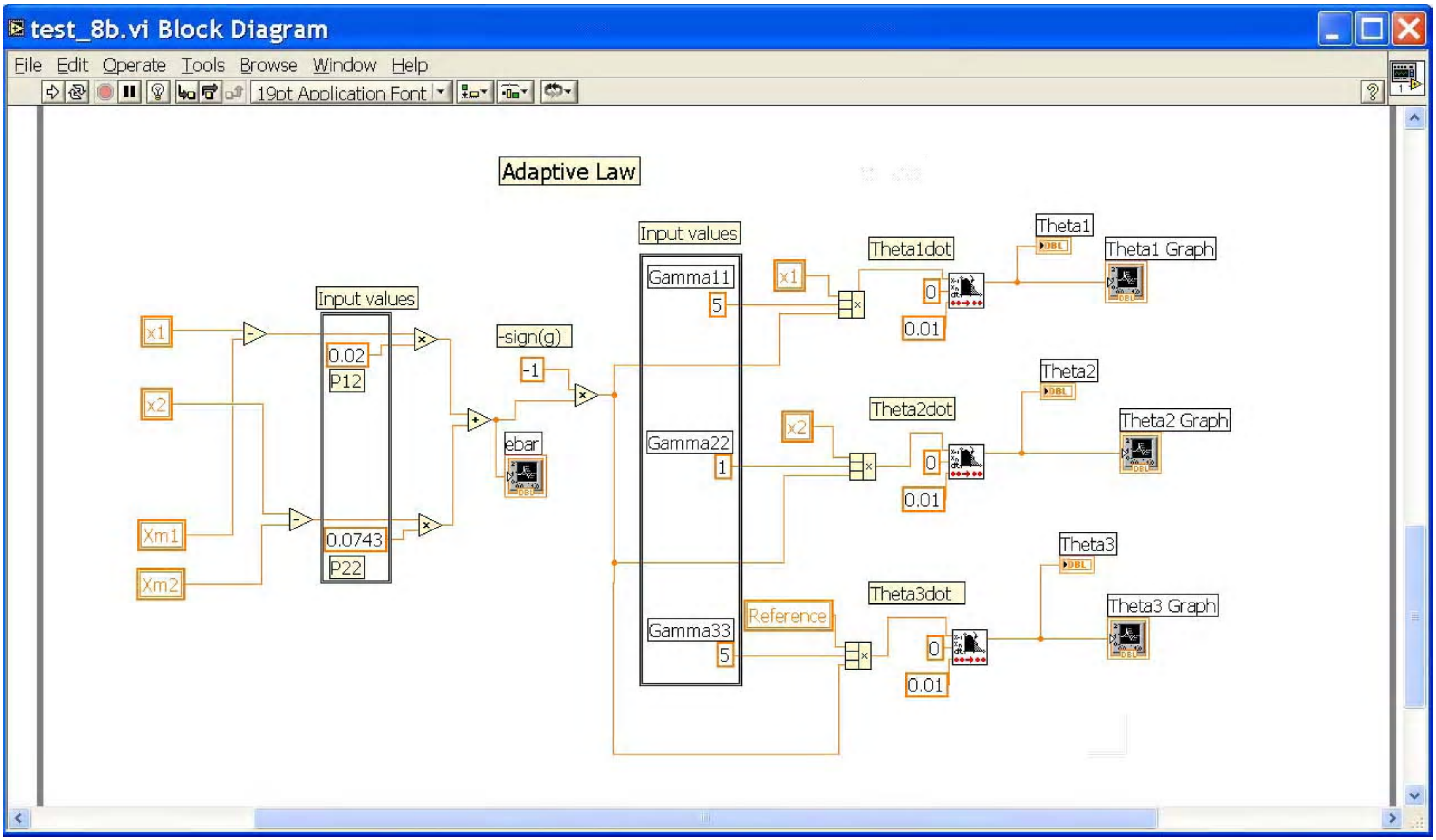


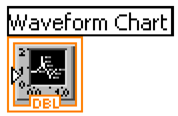
• Important: in your Reports, describe & discuss all your "experimenting" !!!

# 2. Adaptive Control of Angular Position with Full State Measurable



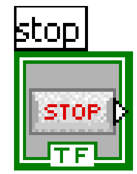
# LabVIEW Function Blocks used for Part 2


Numeric Control

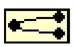



Waveform Chart


DAQ Assistant

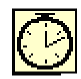



Stop Button

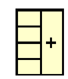


Split Signals

Convert from dynamic data

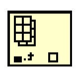


Tick Count (ms)



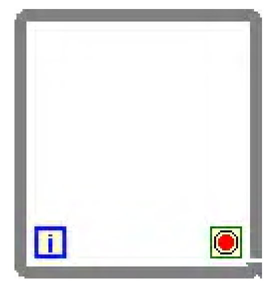
Compound arithmetic


Time Delay

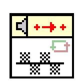


Index array


Mapping and scaling




While Loop



NI_PtbyPt.lvlib:Square Wave PtByPt.vi

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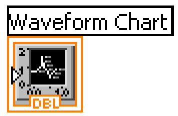
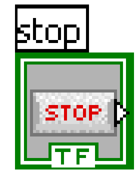
# LabVIEW Function Blocks used for Part 2

Numeric Control

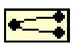


Waveform Chart

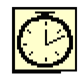
DAQ Assistant

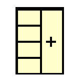


Stop Button

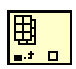

Split Signals


Convert from dynamic data

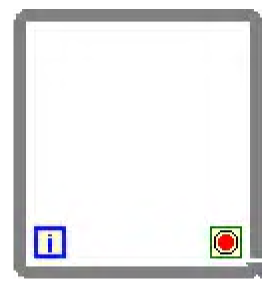

Tick Count (ms)


Compound arithmetic

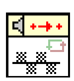
Time Delay

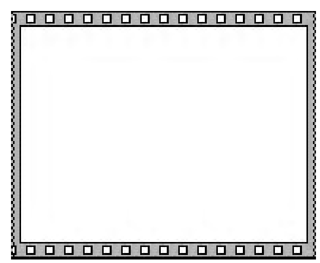

Index array

Mapping and scaling



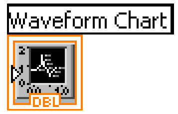
While Loop


NI_PtbyPt.lvlib:Square Wave PtByPt.vi


Flat sequence structure

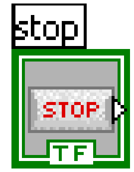
# LabVIEW Functional Blocks used for Part 2


Numeric Control

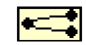



Waveform Chart


DAQ Assistant

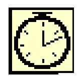



Stop Button

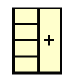


Split Signals

Convert from dynamic data

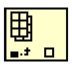


Tick Count (ms)

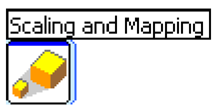


Compound arithmetic

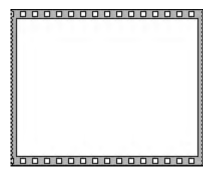

Time Delay



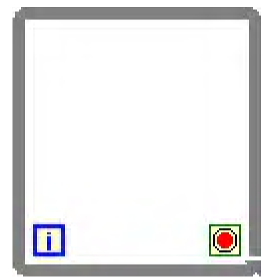
Index array



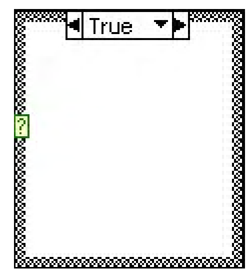

Mapping and scaling



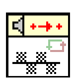
Flat sequence structure



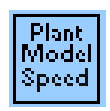
While Loop



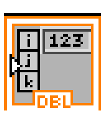

Case Structure



NI_PtbyPt.lvlib:Square Wave PtByPt.vi

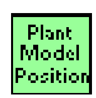



Plant Model Speed (subsystem)



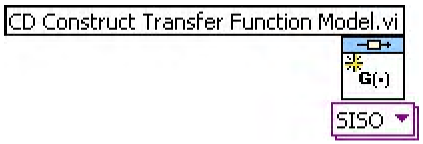

Array of numeric numbers

Equals to 0?

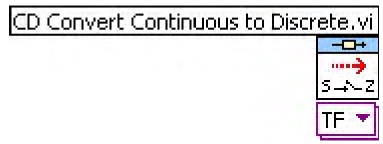



Plant Model Position (subsystem)

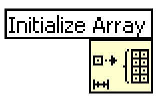
# LabVIEW Functional Blocks used in Part 2



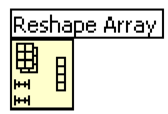

**CD Construct Transfer Function Model.vi**




**CD Convert Continuous to Discrete.vi**

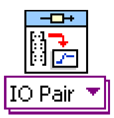



**Initialize Array**

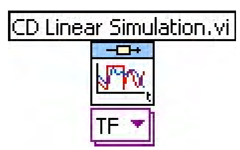



**Reshape Array**


**CD Step Response.vi**

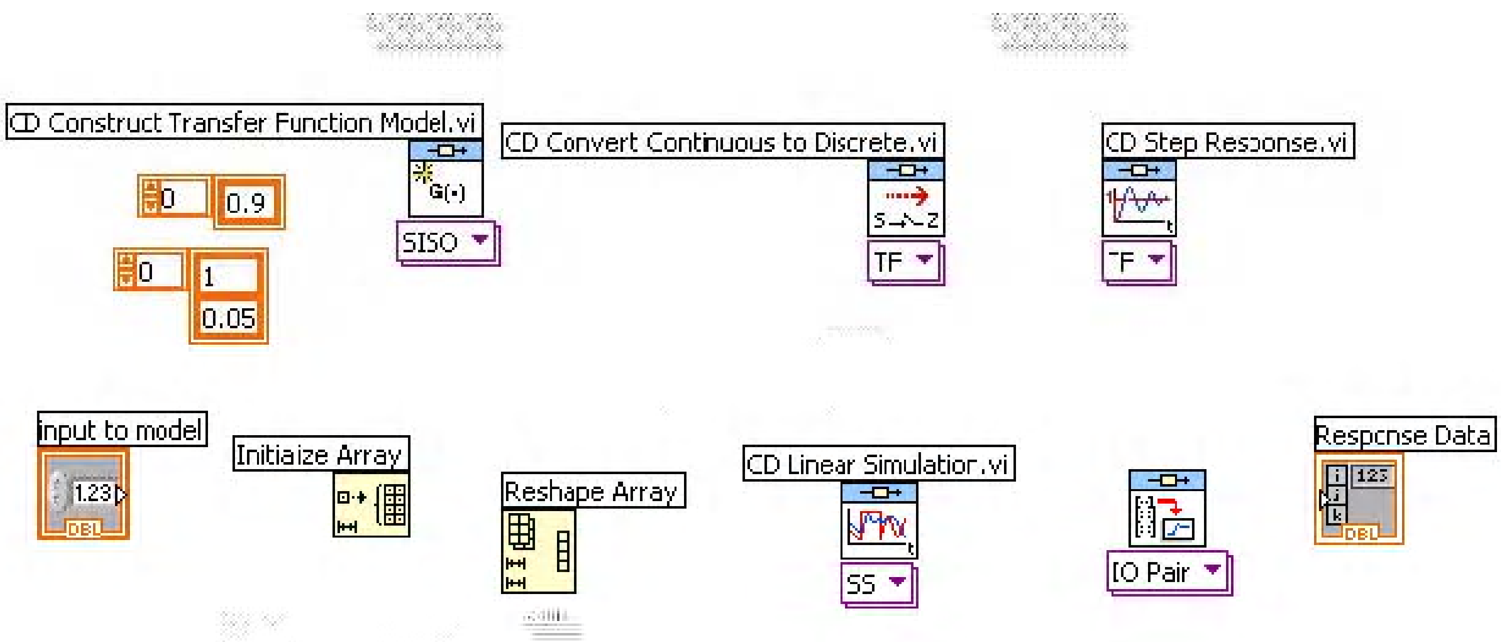



**CD Get IO Time Data.vi**

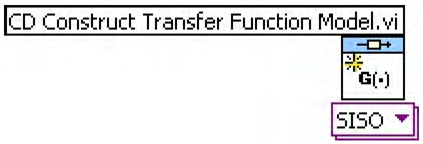



**CD Linear Simulation.vi**

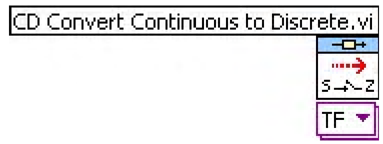
# LabVIEW Functional Blocks used in Part 2



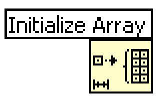
# LabVIEW Functional Blocks used in Part 2



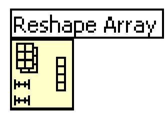

**CD Construct Transfer Function Model.vi**




**CD Convert Continuous to Discrete.vi**

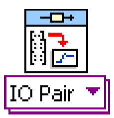



**Initialize Array**

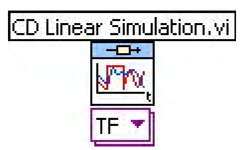



**Reshape Array**


**CD Step Response.vi**

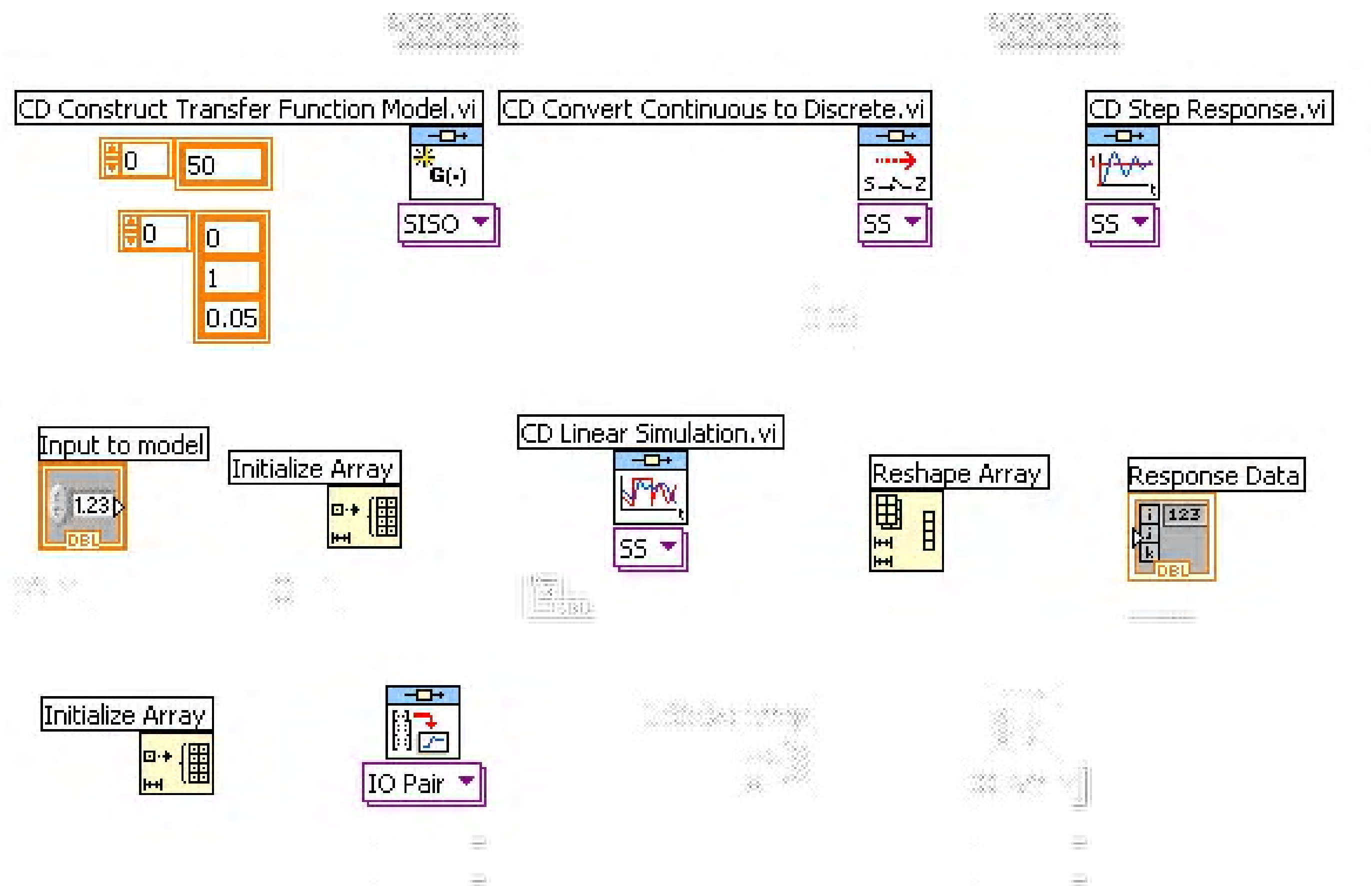



**CD Get IO Time Data.vi**




**CD Linear Simulation.vi**

# LabVIEW Functional Blocks used in Part 2



# 3. Adaptive Control of Angular Velocity (for EE6104 students only!)

- Design and implement an adaptive controller for angular velocity control.
- For the controller, select suitable design choice(s) based on your calibration results in the previous subsection.
- Using the NI LabVIEW system, investigate and explore various design choice(s) for a suitably chosen velocity reference signal. Also show carefully your NI LabVIEW visual programming connections/program.
- Further investigate all signals/variables of suitable interest, and discuss!!! (Sep ~~2009~~ 2018; to note further.)

• Important = in your Reports, describe & discuss all your "experimenting" !!!

[Both EE5104 and EE6104 !!]

NUS National University of Singapore

# Concluding Notes

- CA3 mini-project report (and also CA1 report) are due on:
  - Date: ~~19 Nov 2009~~ 21 Nov 2018
  - Day: ~~Thursday~~ Wednesday
  - Time: ~~12.00 noon~~ 10-30 am
  - ~~Venue to submit report: Control and Simulation Lab, into the "Locked Submission Cabinets", CA1 slot and CA3 slot respectively~~

Submit to IVLE folders!!