Application of an Adaptive Logic Neural Network To Control an Inverted Pendulum System

A Master's Project for the
School of Electronics and Computer Technology
Indiana State University

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February 11, 2000

James Thurber:

"It is better to know some of the questions than all of the answers."

Statement of the Problem

In general, non-linear, time-varying systems are difficult to control in real-time due to the complex nature of the control algorithms necessary to fit the dynamic characteristics of the system.

It is critical to apply a control method that can be executed quickly within the system's response time to achieve and maintain the desired system states.

System Considerations

- System internal structure and boundaries.
  - Machine: Organized simplicity, deterministic.
  - System: Organized complexity.
  - Populations: Unorganized complexity, highly random.
- System’s stability and dynamic characteristics.
- System’s response to environmental conditions.
- Effect of time on the system (e.g. aging, warm-up, wear).

Angeles Arrien:

"The opposite of trusting in the unexpected is trying to control the uncontrollable -- clearly an impossible task."

Control Considerations

- Control objectives and performance measures.
- Linearity and stability of the system.
- Control points affecting system behavior.
- Limitations in the available control energy.
- Accuracy and resolution of system feedback.
- Effects of uncontrolled environmental forces.
- Safety and system operating constraints.

Control Method

(1 of 2)

- The design method does not require an explicit mathematical model of the system.
- The design method uses sample data to derive the control algorithm.
- The design method is applicable to both linear and non-linear systems.
- The control method is fast enough to provide real-time control of high-speed systems.
- The control method meets the control accuracy requirements.

Control Method

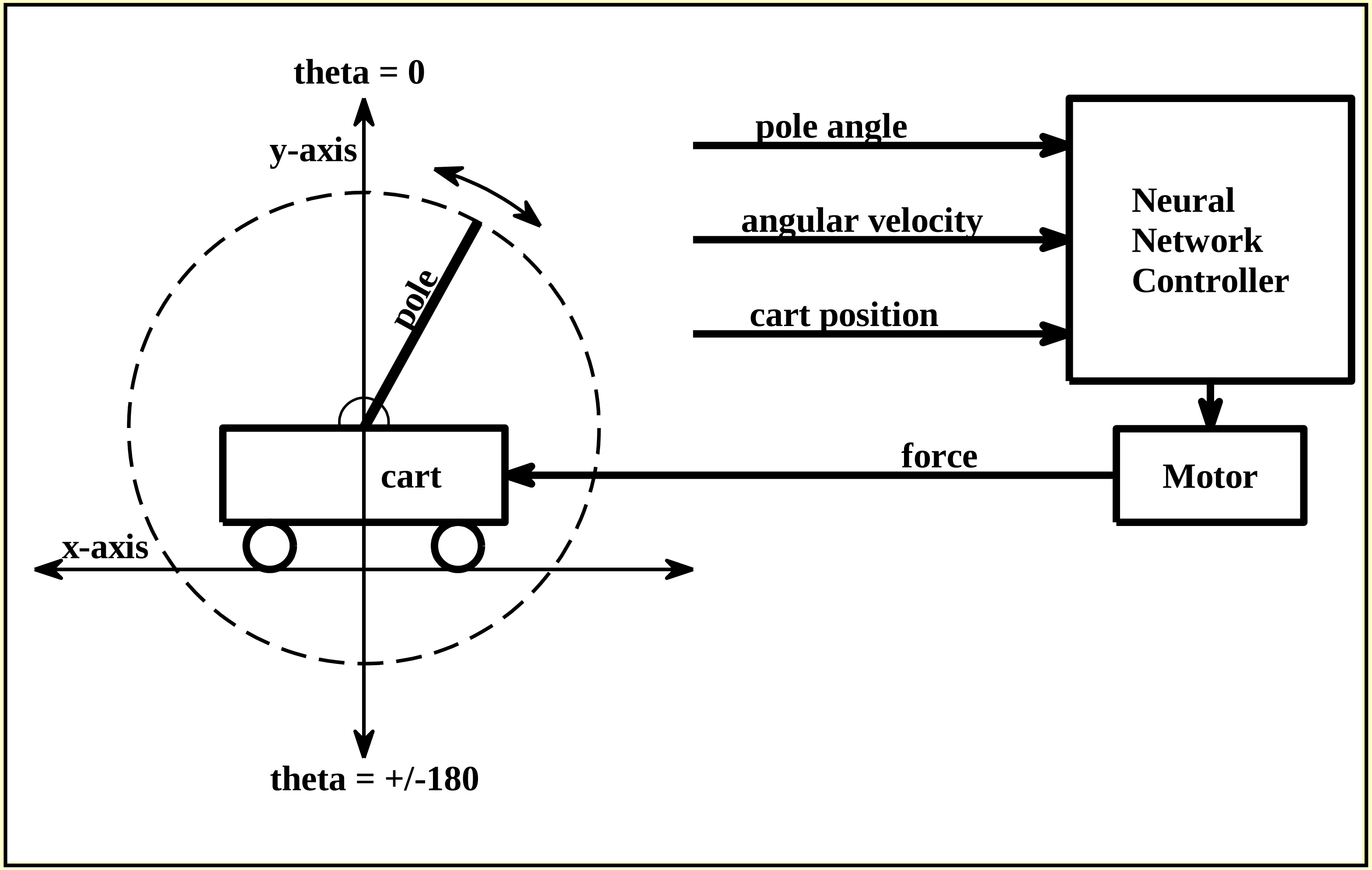
(2 of 2)

- The control method meets stability requirements.
- The control method is sufficiently robust in the presence of disturbances in the system.
- The control method minimizes the cost of control effort required to achieve the control objectives.
- The control method is continuous throughout its entire control space.
- The control methods input-output mappings are obtainable throughout its entire control space.

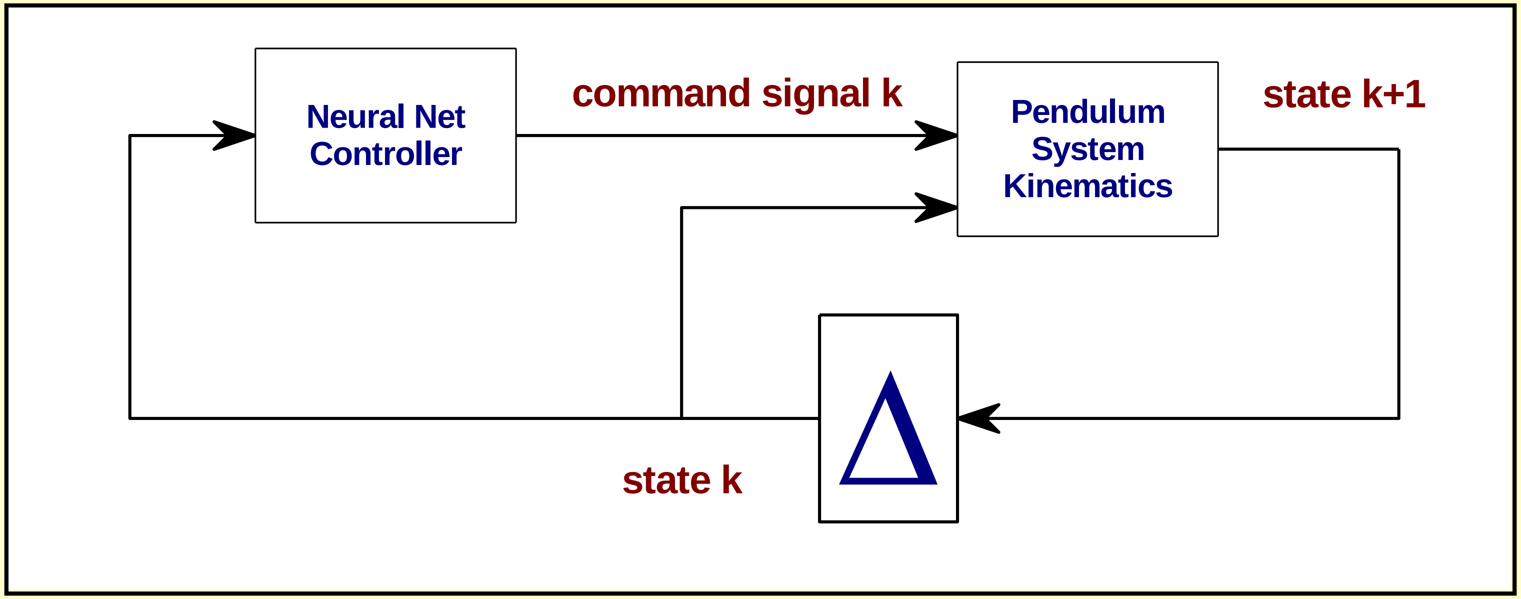
Definitions

- **Artificial Neural Network** (ANN) - Engineered computational systems modeled after or inspired by the learning abilities and parallelism of biological nervous systems .
- **Adaptive Logic Network** (ALN) - A type of artificial neural network used to synthesize piecewise linear and continuous functions.
- **Supervised Learning** - The task of learning the mapping from a vector of inputs to a vector of targets or desired outputs. "Learning" means adjusting a vector of weights or parameters in an ANN based on the data contained in a static database of values.
- **Neurocontrol** - The use of well specified neural networks - artificial or natural - to emit actual control signals.

Simple Pendulum System

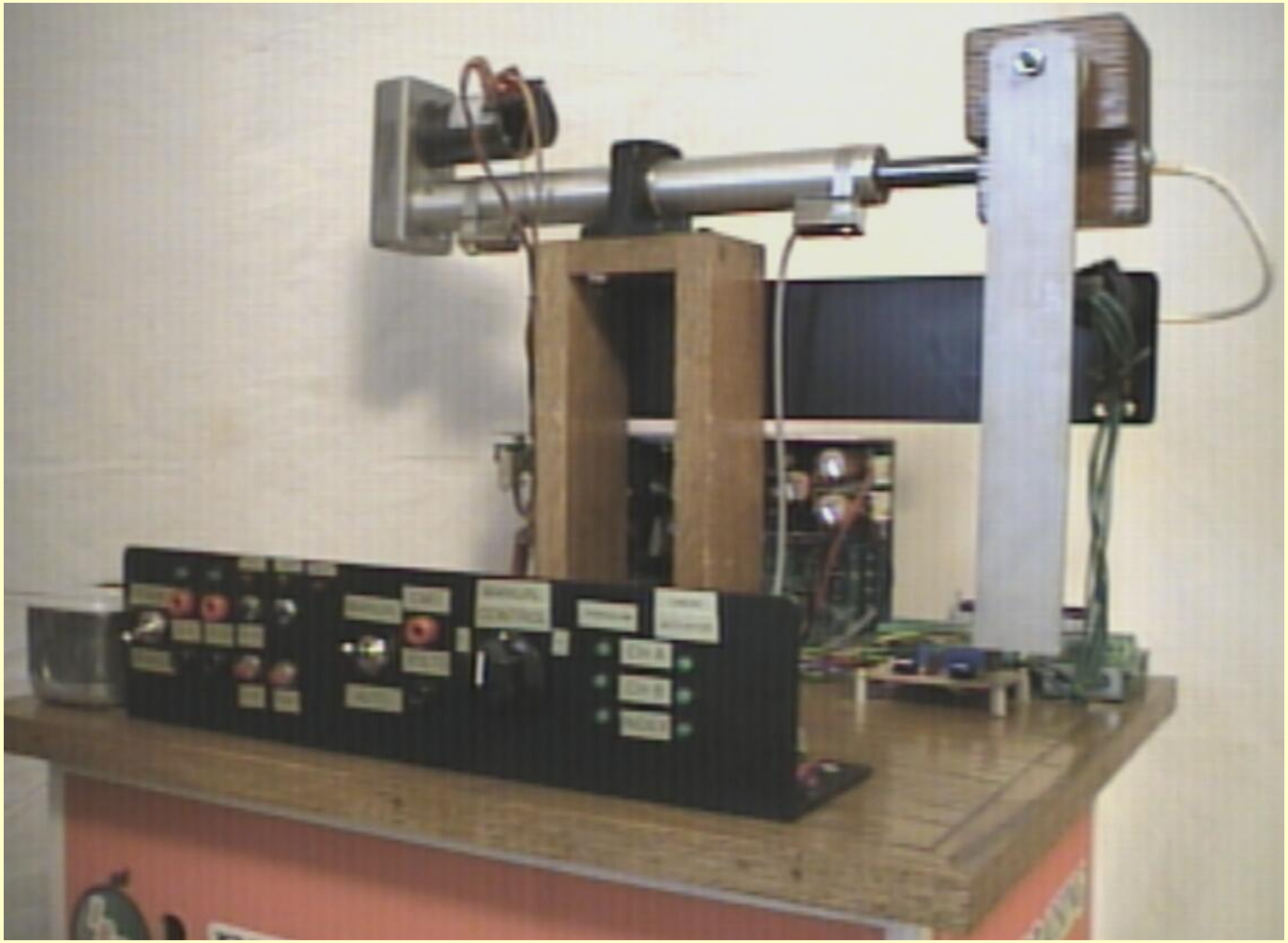


Pendulum State Diagram

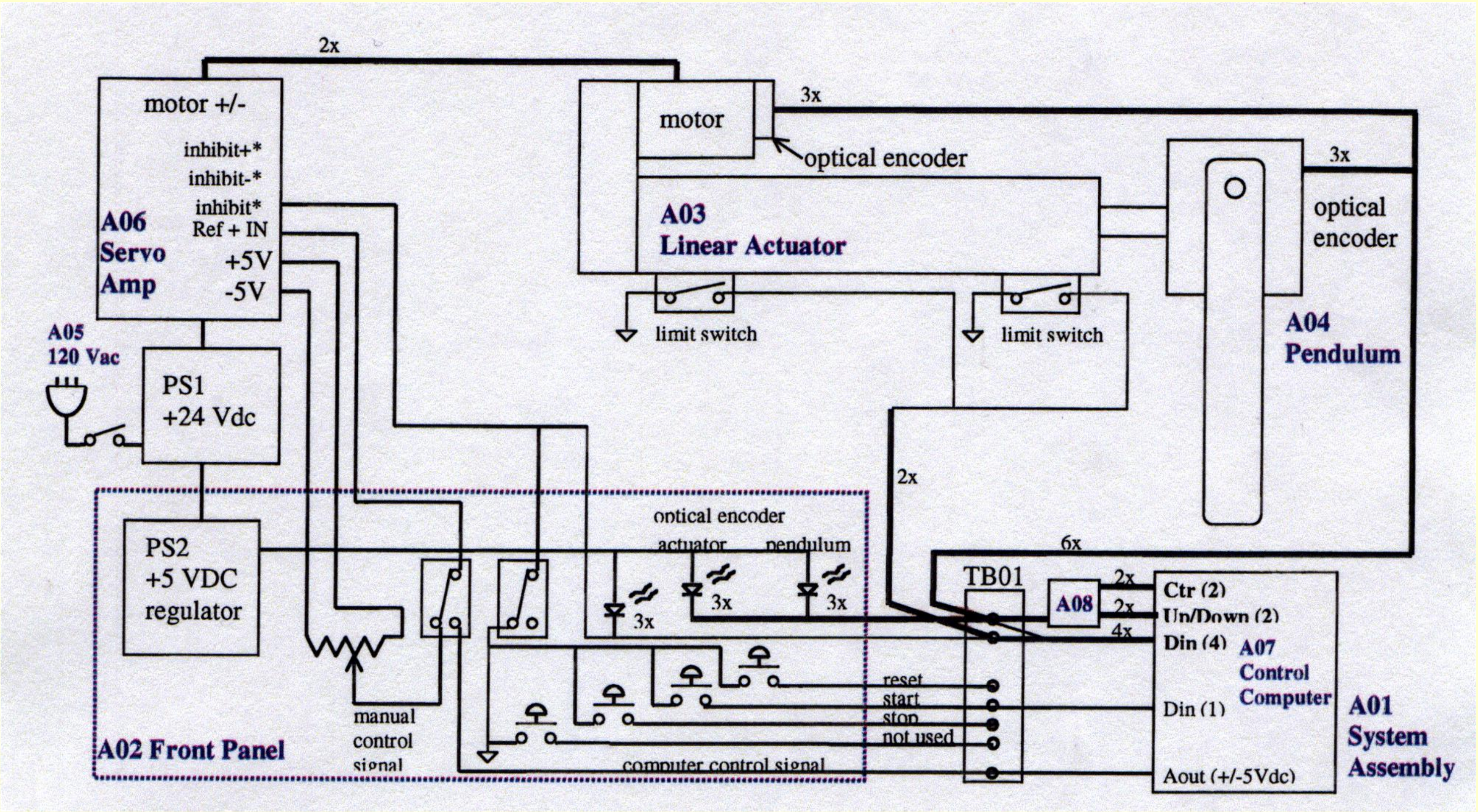


Simple state block diagram

Pendulum Apparatus



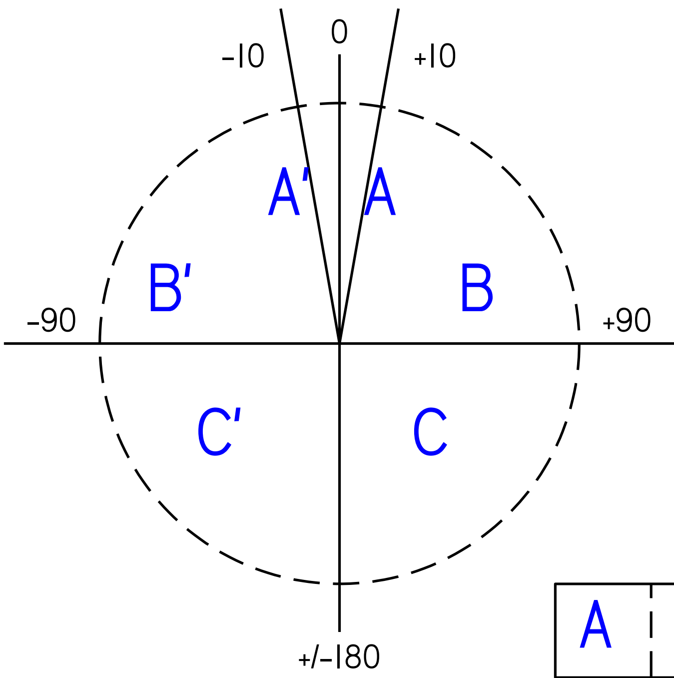
Apparatus Block Diagram



Assembly Definitions

Assy	Description	Description
A01	System Assembly	All assemblies, parts and wiring not specifically included in another assembly.
A02	Front Panel Assembly	All parts and wiring included in the front panel interface.
A03	Linear Actuator Assembly ***(corresponds to cart)***	All parts and wiring included in the linear actuator assembly. Includes linear actuator motor, shaft, limit switches and optical encoder.
A04	Pendulum Assembly ***(corresponds to pole)***	All parts and wiring included in the pendulum assembly. Includes the pendulum pole and optical encoder.
A05	AC & DC Power Distribution	All electrical power distribution wiring including 120 VAC wiring and + 24 VDC power.
A06	Servo Amplifier	Converts low-level control signals into the high power levels for driving the linear actuator motor.
A07	Control Computer ***(neural network controller)***	Reads digital, analog and counter input values from the pendulum apparatus and sends low-level control commands to the servo amplifier assembly.
A08	Position Decode Assembly	Converts outputs from optical encoders into digital pulse train and up/down direction signals for counter inputs in the control computer A07.

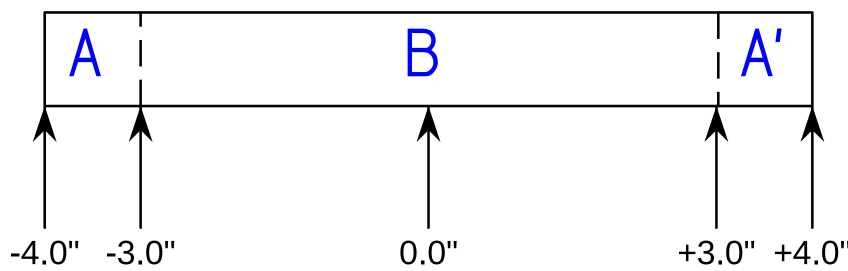
Critical Control Points



Velocity Ranges

Negative Fast	- 700 deg/sec
Negative Medium	- 500 deg/sec
Negative Slow	- 100 deg/sec
Zero	0 deg/sec
Positive Slow	+ 100 deg/sec
Positive Medium	+ 500 deg/sec
Positive Fast	+ 700 deg/sec

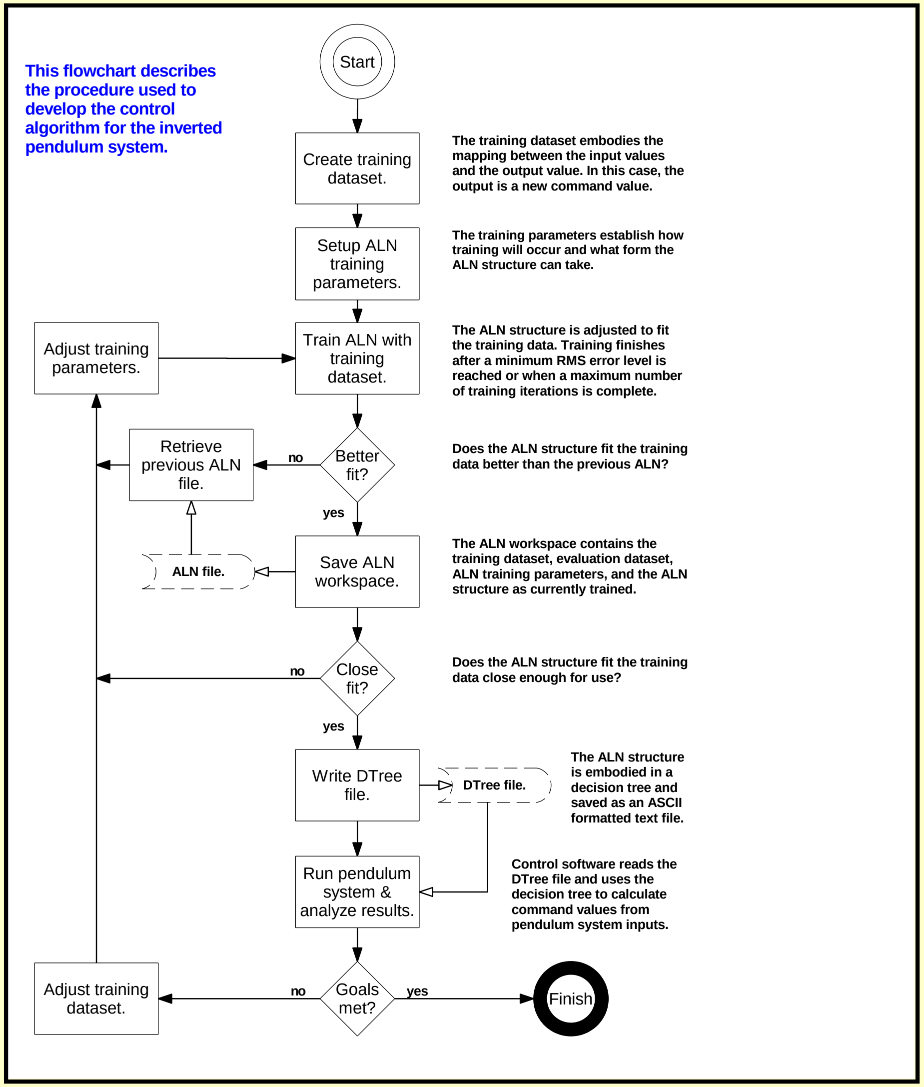
Cart Position



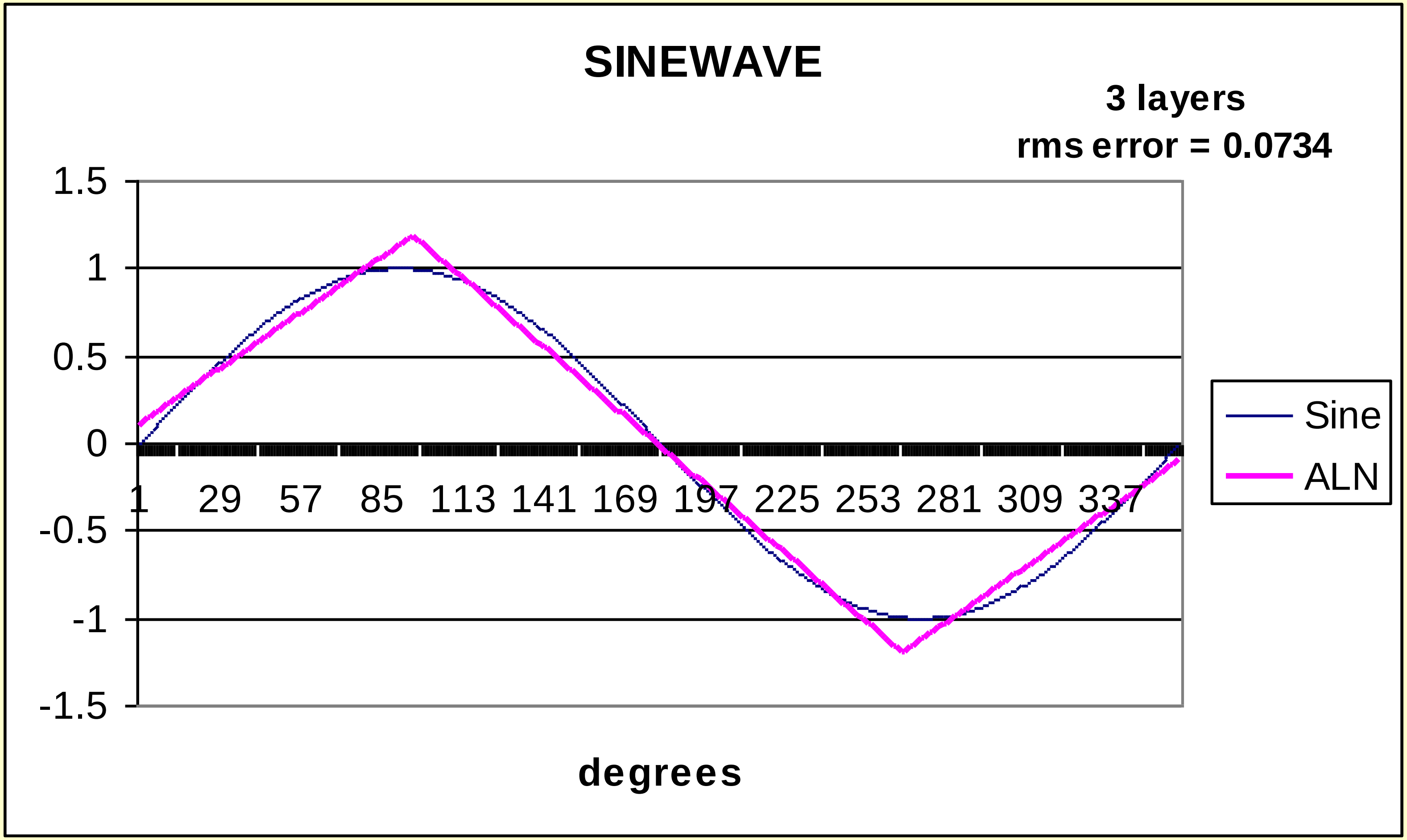
Aldous Huxley:

“Experience is not what happens to a man; it is what a man does with what happens to him.”

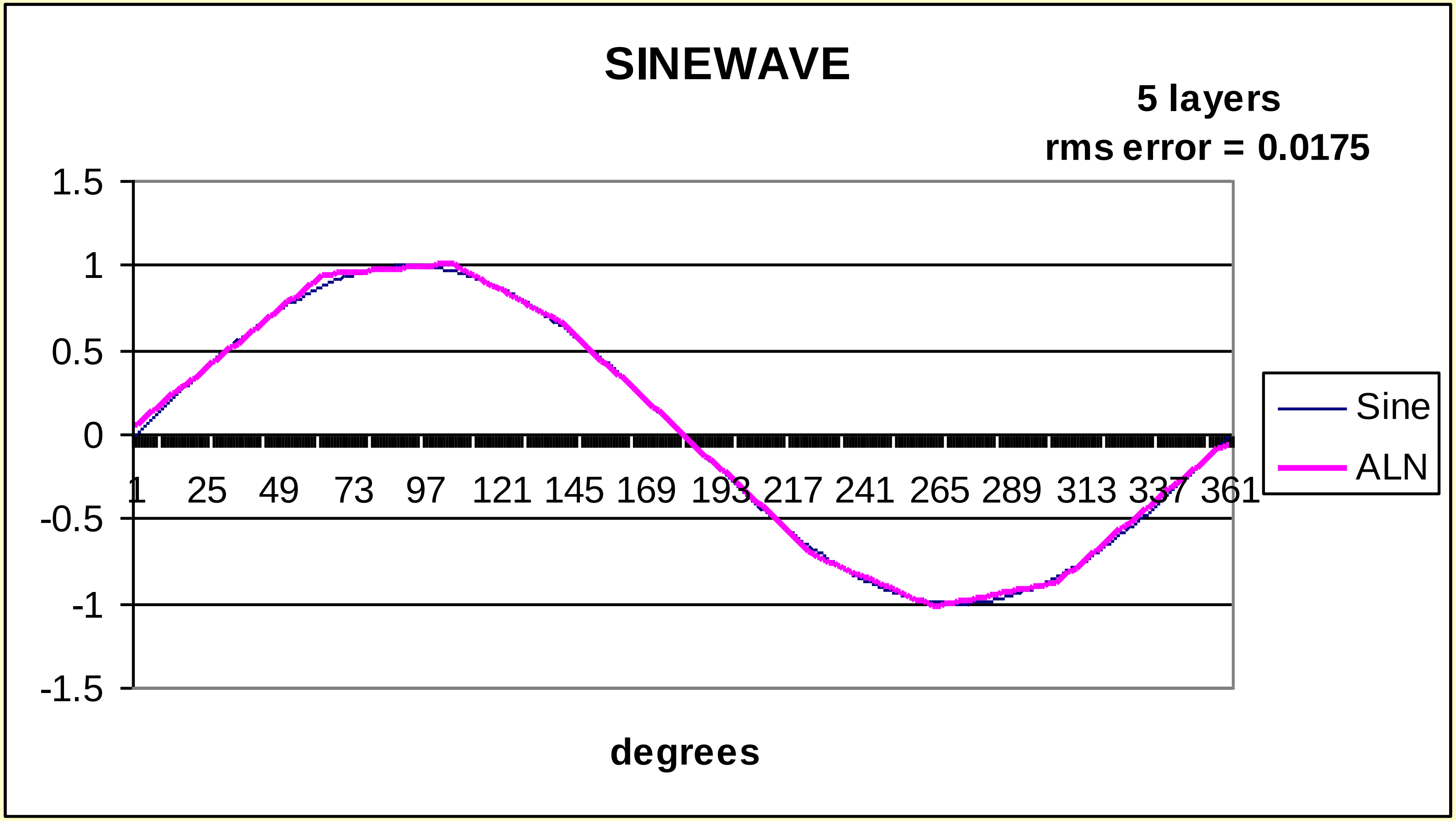
Control Development Procedure



ALN Bench Software



ALN Bench Software



ALN Bench Software

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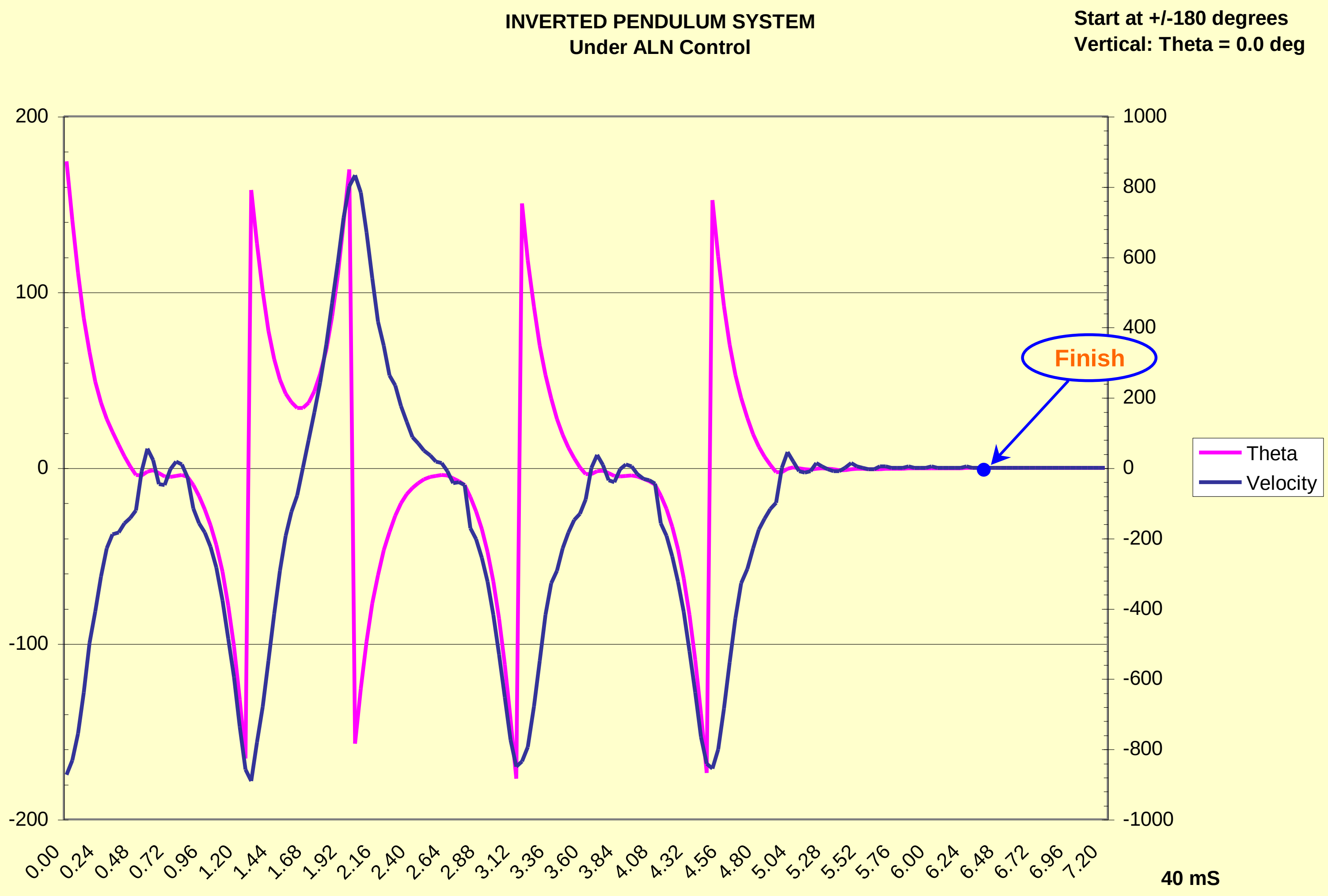
- // Sine3Layer.dtr exported on Fri Feb 11 06:32:37 2000
- // ALN Decision Tree file format v1.0 (C)1994 Dendronic Decisions Limited
- **VERSION = 1.0;**
- **VARIABLES = 2;**
- x0 : [-1.7976931348623157e+308, 1.7976931348623157e+308];
- x1 : [-1.7976931348623157e+308, 1.7976931348623157e+308];
- **OUTPUT = x1;**
- **LINEARFORMS = 4;**
- 0 : 4.9863553047180175e-005 (x0 - 354) - 1 (x1 + 0.104528463);
- 1 : 0.011341813119205551 (x0 - 311.26616581180406) - 1 (x1 + 0.65895805563533916);
- 2 : 0.010824275499934338 (x0 - 54.461837072461876) - 1 (x1 - 0.72072839836838765);
- 3 : -0.014086080160059843 (x0 - 168.75895402496039) - 1 (x1 - 0.16963986125886968);
- **BLOCKS = 2;**
- 0 : MAX(MIN(0, 1), 2);
- 1 : MAX(MIN(0, 1), MIN(2, 3));
- **DTREE = 3;**
- 0 : (x0 <= 0) ? 1 : 2;
- 1 : block 0;
- 2 : block 1;

SUCCESS!!


INVERTED PENDULUM SYSTEM
Under ALN Control
Start at +/-180 degrees
Vertical: Theta = 0.0 deg
200
100
0
-100
-200
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Finish
Theta
Velocity
0.00
0.24
0.48
0.72
0.96
1.20
1.44
1.68
1.92
2.16
2.40
2.64
2.88
3.12
3.36
3.60
3.84
4.08
4.32
4.56
4.80
5.04
5.28
5.52
5.76
6.00
6.24
6.48
6.72
6.96
7.20
40 mS

SUCCESS!!

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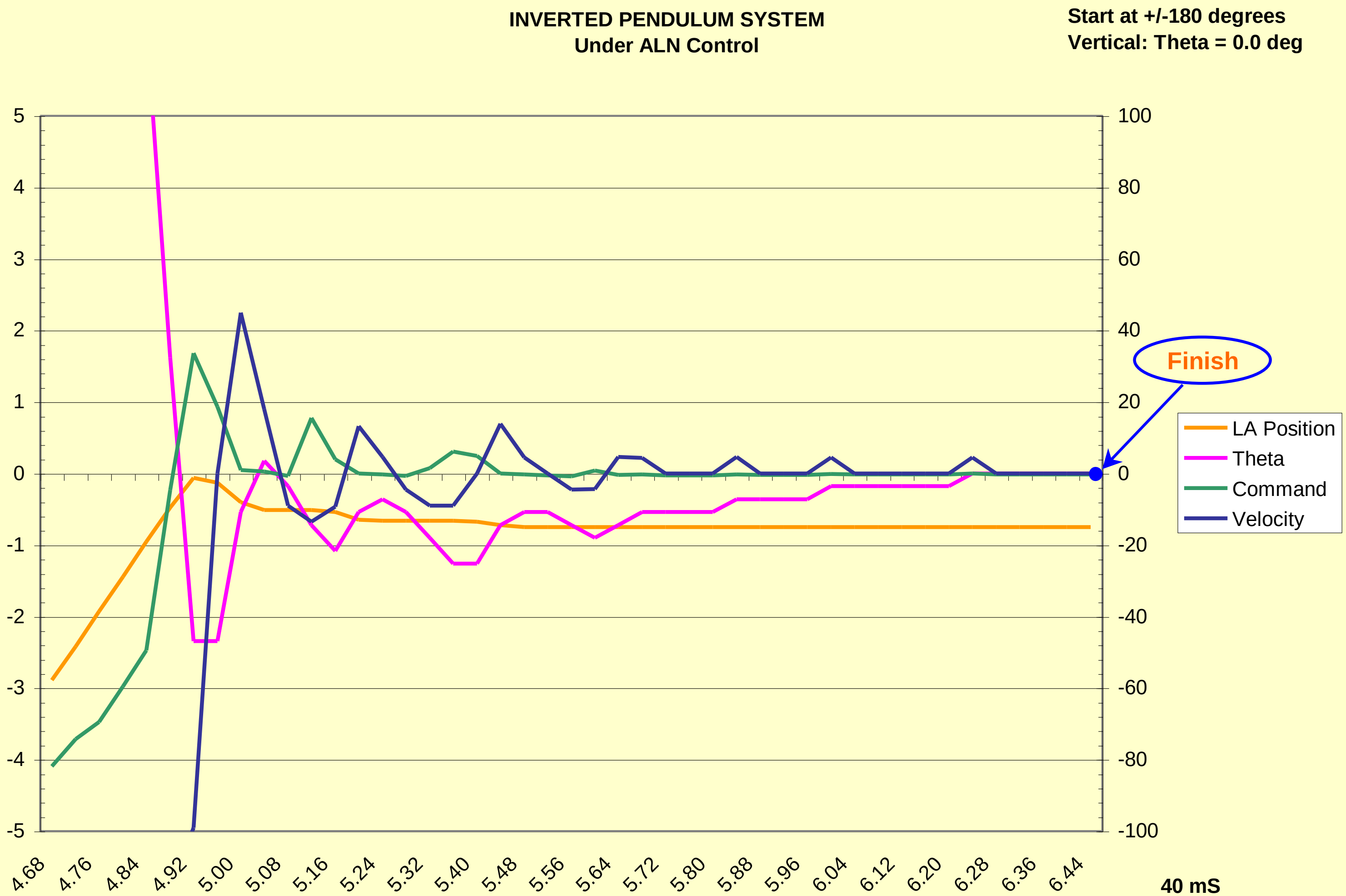


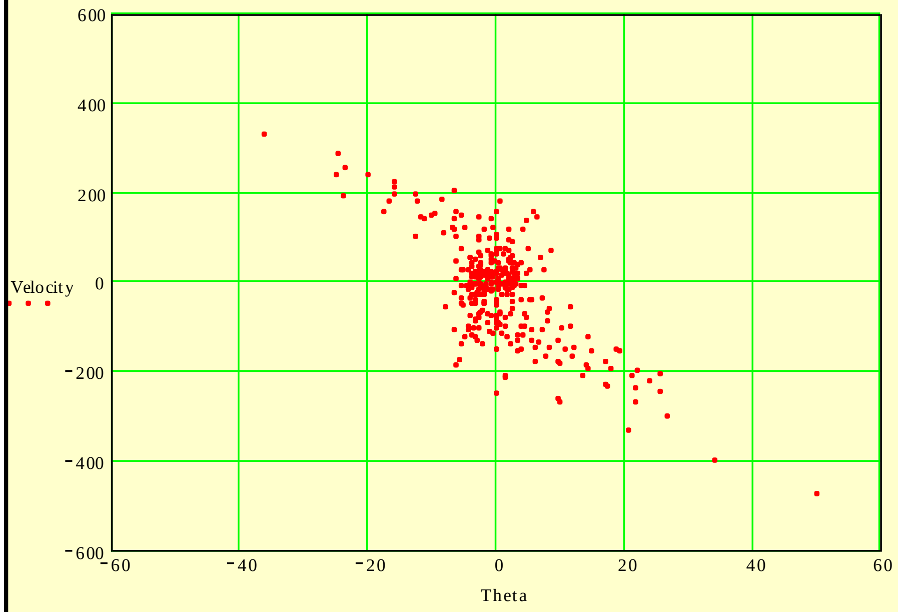
Control Envelope Achieved

Measurement Data

1. Error values (theta) between +/- 90 degrees.
2. Linear actuator position between +/-3.0 inches.
3. Success defined as error between +/- 4 .0 degrees and velocity less than 10.0 degrees/second. Measurement data points leading-up to a successful data point were included in the analyzed dataset.

Descriptive Statistics

	Min	Max
Error	-36.18	69.12
Velocity	-603	328.50



Margaret Drabble:

"When nothing is sure, anything is possible."

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