Chapter 3: Method of Investigation

OVERVIEW

In order to evaluate the feasibility of using an ALN type neural network on a PC-based controller to provide effective control of a non-linear, time-varying system, the methodology of the research efforts needs to be fully defined. This chapter defines and explains the procedures employed as well as identifies the critical characteristics of the hardware apparatus and software used for this experiment. The research design and the description of the measures employed are also discussed in this chapter.

DESCRIPTION OF SUBJECTS AND EQUIPMENT

In preparation for exploring the application of an ALN type neural network control method, an inverted pendulum system has been designed and built to act as the test platform. The inverted pendulum system is non-linear, time-varying and inherently unstable. The control objective is to cause the pendulum achieve and sustain an inverted state (theta = 0) using an ALN type neural network to implement the control algorithm. **Figure 1** is a simple representation of the pendulum system from a theoretical viewpoint, and **Figure 2** is a simple state diagram representation of the same system.

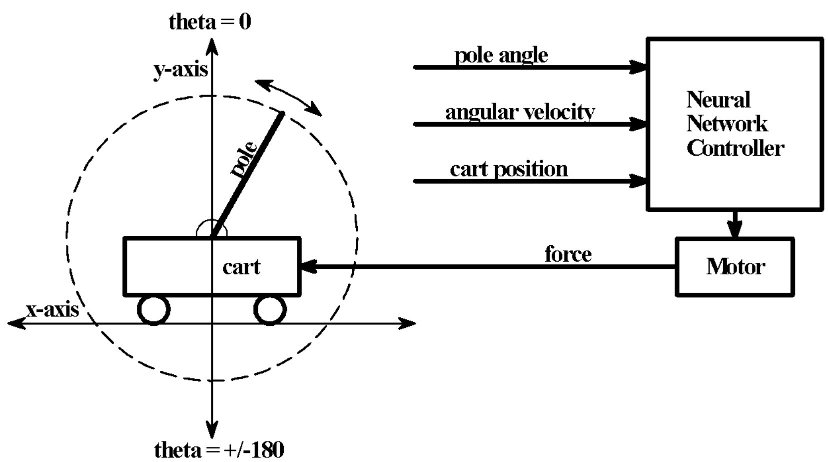


Figure 1: Simplified cart/pole pendulum system.

The following describes the major components of the test apparatus as they correspond to the simplified system represented in **Figure 1**. The horizontal motion represented by the **cart and motor** was provided by a linear actuator assembly consisting of a DC servomotor connected to an Acme lead screw inside a moveable shaft, with an optical encoder for feedback to the controller. The **pole** consisted of a 1.25 lb. flat aluminum bar 3/16 inches thick, 1.5 inches wide, and 10.6 inches long. The pole was attached to a bearing allowing 360 degrees of circular motion and mounted to the horizontal shaft of the linear actuator, with an optical encoder for feedback. The **neural network controller** consisted of an IBM-compatible personal computer and a National Instruments data acquisition card. Application software, written in LabVIEW 5, executed a real-time loop (40 mS loop time) that read the horizontal position of the linear actuator and angular position of the pendulum pole, calculated dynamic values (e.g. velocity), and derived the new command values that were then written to the data acquisition card. A servo amplifier then provided high-power control voltage to the linear actuator motor based on the low-level command voltage from the data acquisition card.

See **Figure 3** through **Figure 8** for color photographs of the pendulum apparatus. A top-level system block diagram is shown in **Figure 9** and **Table 1** describes each assembly as shown on the system block diagram. The detailed hardware design documents and specifications for the inverted pendulum system are published in a report created for ECT 603b.

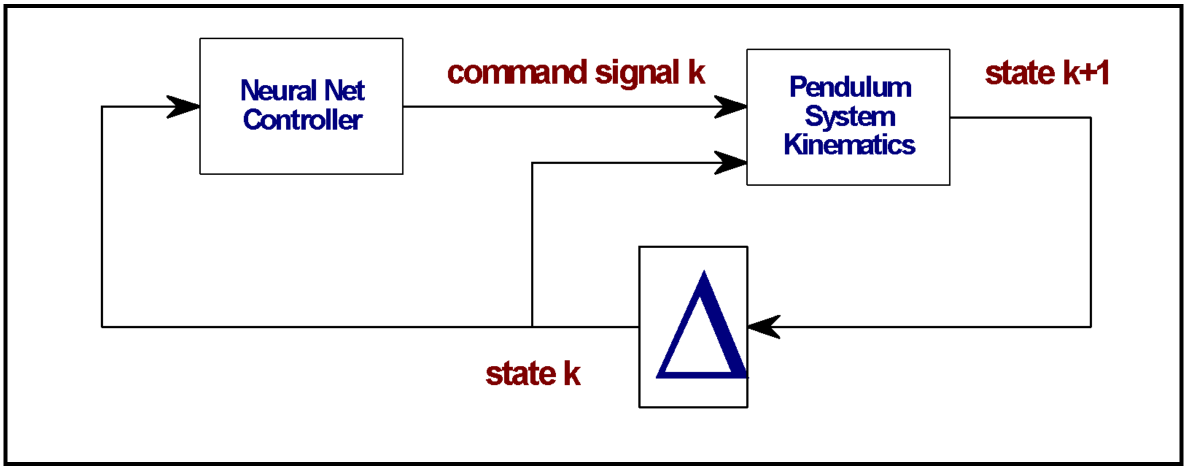


Figure 2 : Simple state block diagram.

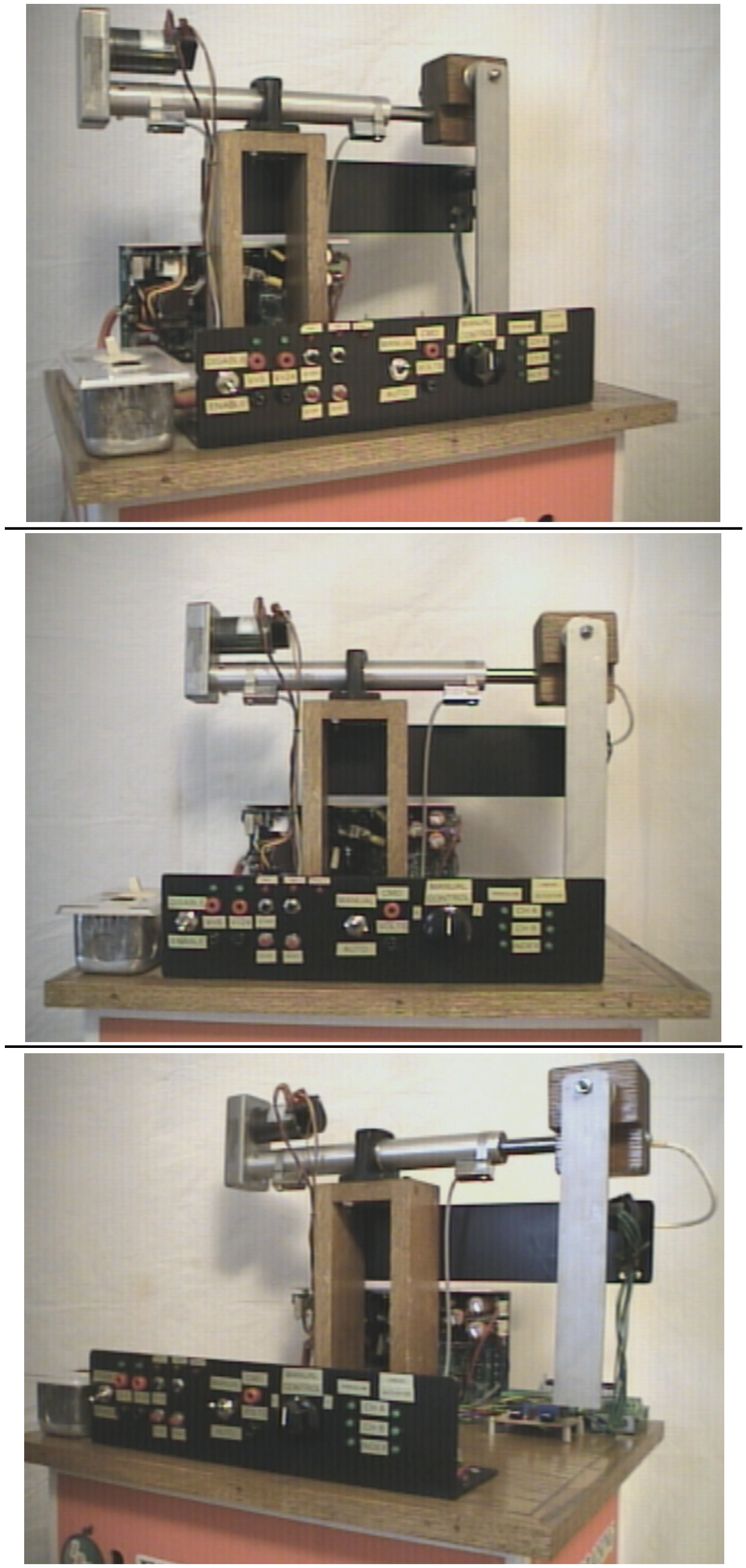


Figure 3 : Pendulum Apparatus Photographs (1 of 6)

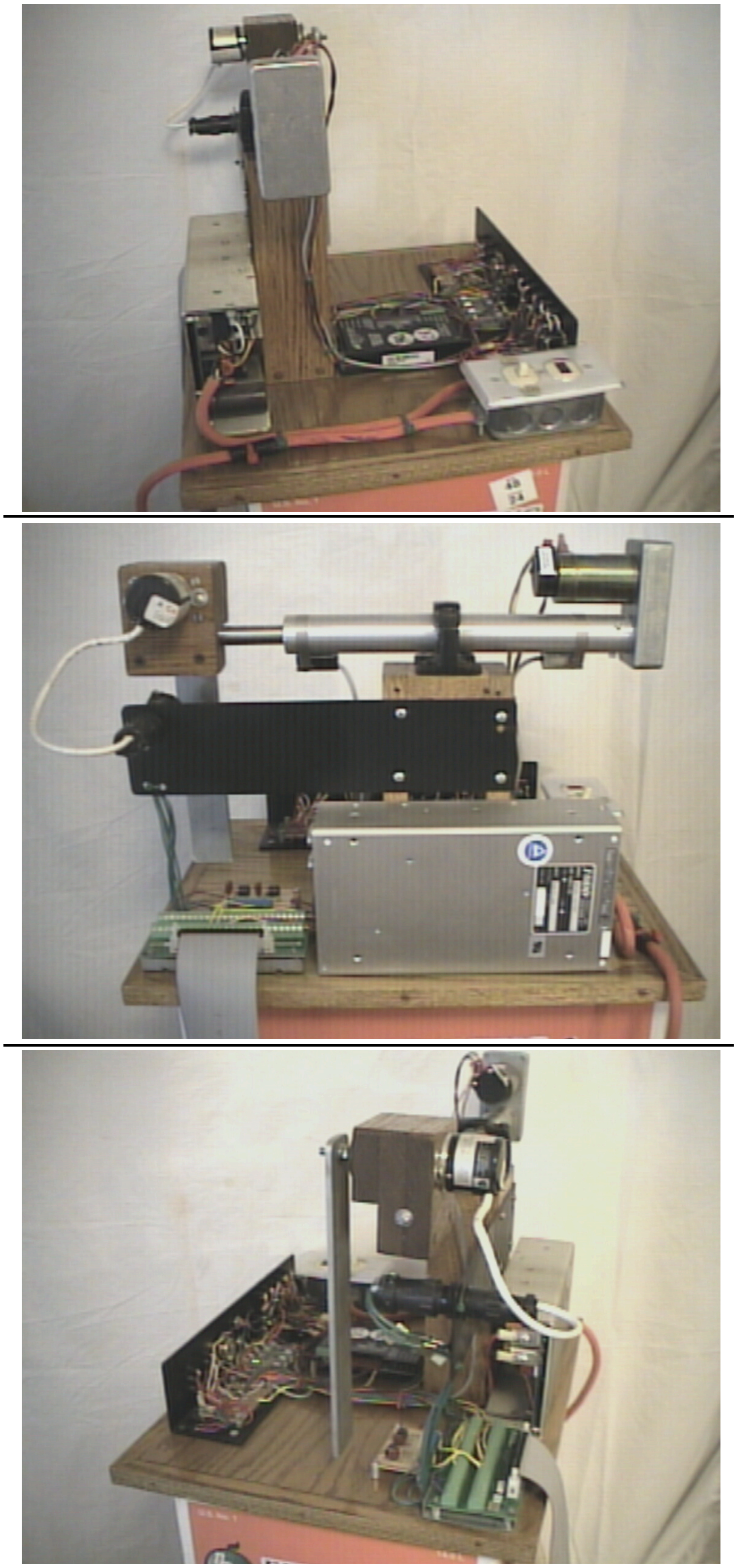


Figure 4 : Pendulum Apparatus Photographs (2 of 6)

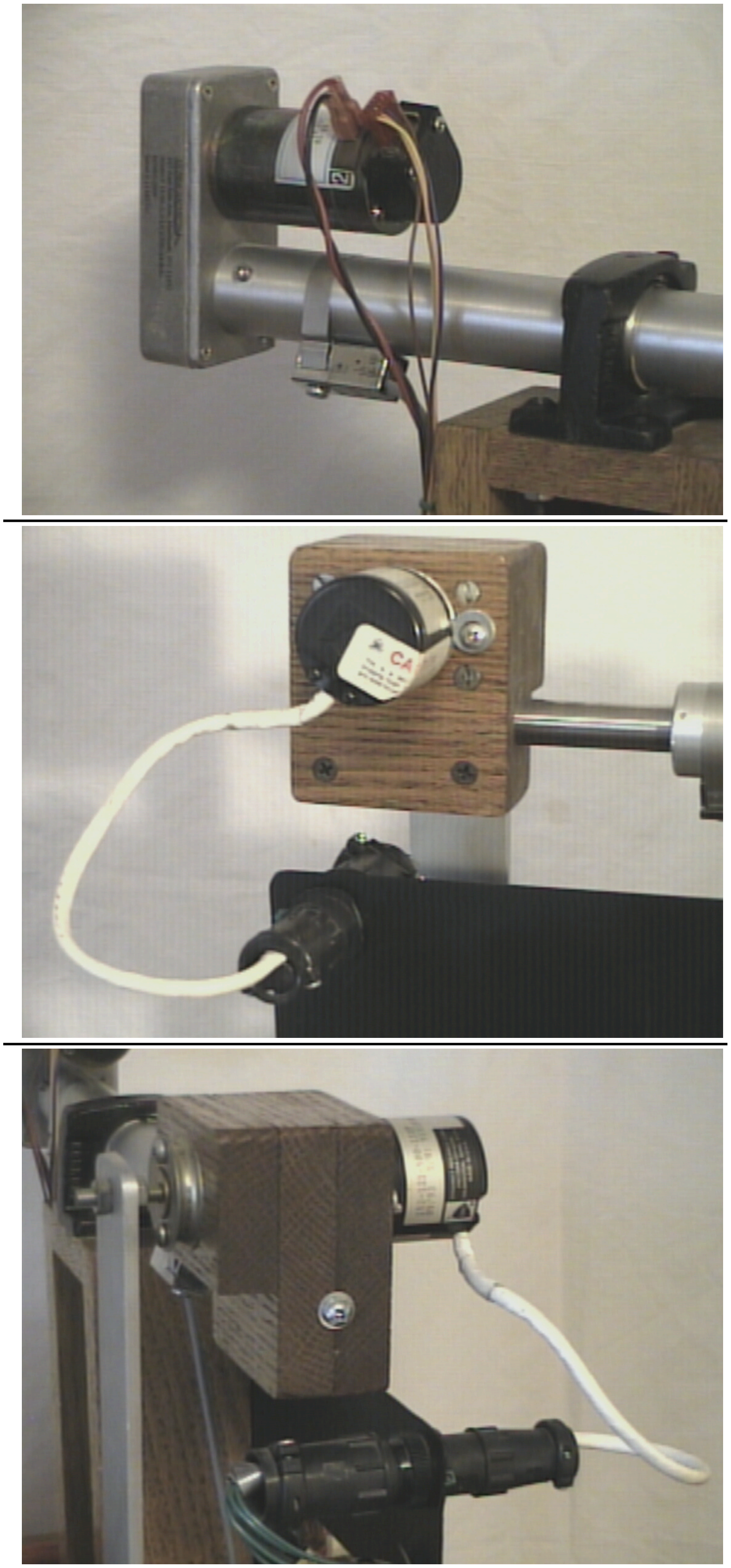


Figure 5 : Pendulum Apparatus Photographs (3 of 6)

Figure 6 : Pendulum Apparatus Photographs (4 of 6)

Figure 7 : Pendulum Apparatus Photographs (5 of 6)

Figure 8 : Pendulum Apparatus Photographs (6 of 6)

Inverted Pendulum System Architecture

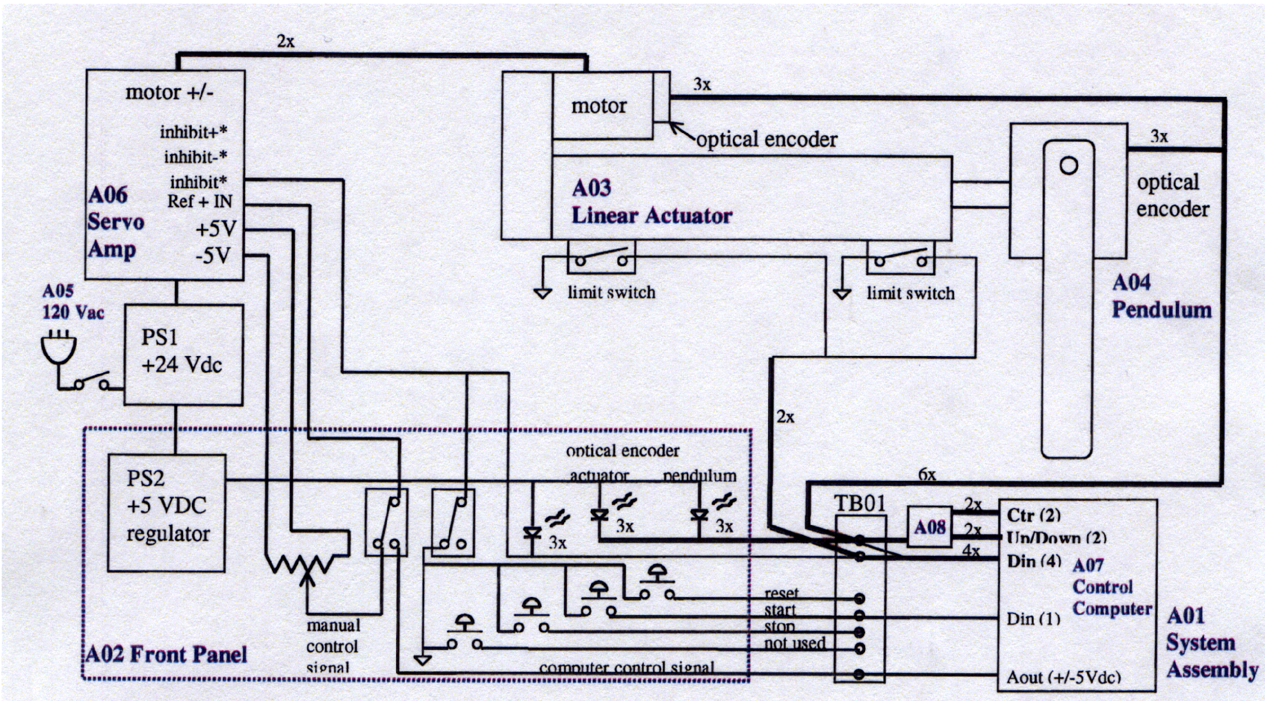


Figure 9: System block diagram.

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 voltage 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.

Table 1: System assembly descriptions.

System Controller I/O Definitions

The AT-MIO-16E-10 I/O card is multifunction analog, digital and timing I/O board for an IBM compatible PC AT computer. This board features two 12-bit DAC output voltage channels with sixteen 12-bit ADC input channels that can also be configured as eight differential input channels. The board also provides eight channels of digital I/O lines, and two up/down counter/timer channels. The board can be installed in 16-bit ISA expansion slot on a PC AT computer. Table 2 summarizes the I/O assignments.

Computer Port I/O	Description	Connector Pin
ACH 0	**Used for servo-amplifier control signal feedback.**	**3**
ACH 1	Analog input channel 1. Not used.	5
ACH 2	Analog input channel 2. Not used.	7
ACH 3	Analog input channel 3. Not used.	9
ACH 4	Analog input channel 4. Not used.	11
ACH 5	Analog input channel 5. Not used.	13
ACH 6	Analog input channel 6. Not used.	15
ACH 7	Analog input channel 7. Not used.	17
ACH 8	Analog input channel 8. Not used.	4
ACH 9	Analog input channel 9. Not used.	6
ACH 10	Analog input channel 10. Not used.	8
ACH 11	Analog input channel 11. Not used.	10
ACH 12	Analog input channel 12. Not used.	12
ACH 13	Analog input channel 13. Not used.	14
ACH 14	Analog input channel 14. Not used.	16
ACH 15	Analog input channel 15. Not used.	18
AISENSE	Analog input sense. Not used.	19
AIGND	Analog input ground. Not used.	1,2
DAC0OUT	**Control signal for servo-amplifier.**	**20**
DAC1OUT	Analog output channel 1. Not used.	21
EXTREF	External reference for DAC inputs. Not used.	22
AOGND	**Analog output ground.**	**23**
DIO 0	**Linear actuator limit switch – extended.**	**25**
DIO 1	**Linear actuator limit switch – retracted.**	**27**
DIO 2	**Index of optical encoder for pendulum.**	**29**
DIO 3	**Servo-motor inhibit switch input.**	**31**
DIO 4	**Front panel auto/manual switch input.**	**26**
DIO 5	**Front panel start switch input.**	**28**
DIO 6	**Counter 0 up/down input. Used for pendulum position.**	**30**
DIO 7	**Counter 1 up/down input. Used for linear actuator position.**	**32**
DGND	**Digital ground.**	**24,33**
+5 V	Not used.	34,35
SCANCLOCK	Scan clock output signal. Not used.	36
EXTSTROBE*	External strobe output signal. Not used.	37
PFI0/TRIG1	PFI 0 or Trigger 1 input/output signal. Not used.	38
PFI1/TRIG2	PFI 1 or Trigger 2 input/output signal. Not used.	39
PFI2/CONVERT*	PFI 2 or Convert input/output signal. Not used.	40
PFI3/GPCTR1_SOURCE	**Linear actuator position counter input.**	**41**
PFI4/GPCTR1_GATE	PFI 4 or General-purpose counter 1 gate. Not used.	42
GPCTR1_OUT	Terminal count output for counter 1. Not used.	43
PFI5/UPDATE*	PFI 5 or Update input/output signal. Not used.	44
PFI6/WFTRIG	PFI 6 or Waveform trigger input/output signal. Not used.	45
PFI7/STARTSCAN	PFI 7 or Start scan input or output. Not used.	46
PFI8/CTR0_SOURCE	**Pendulum position counter input.**	**47**
PFI9/GPCTR0_GATE	PFI 9 or General-purpose counter 0 gate. Not used.	48
GPCTR0_OUT	Terminal count output for counter 0. Not used.	49
FREQ_OUT	AT E Series board frequency output. Not used.	50

Table 2: National Instruments AT-MIO-16E-10 I/O assignment table.

RESEARCH DESIGN AND PROCEDURES

ALN I/O Variables

Initially, one can consider a neural network as a black box entity that converts or maps input variables into one or more output variables using some sort of mapping technique. In pendulum system, there are three input variables and one output variable. Refer to **Table 3** for parametric details of each variable.

Two ALN variables, linear actuator and pendulum position, are read from the AT-MIO-16E-10 board's two up/down counters. For both variables, a hardware circuit converts the 2-bit Gray code output from the optical encoder into a pair of digital signals consisting of a pulse train and an up/down direction signal. Each change in the gray code bit pattern causes the pulse train to change logic states and at the same time update the direction signal. This conversion function is performed by an LS7084 integrated circuit from LSI Computer Systems, Inc. Each pair of linear actuator and pendulum digital signals from this circuit drives a corresponding counter input on the AT-MIO-16E-10 board.

Pendulum velocity is a calculated value derived from the previous and most recent position measurements.

ALN Variable Signal Name	$\mathbf{X_0}$ Linear Actuator Position	$\mathbf{X_1}$ Pendulum Velocity	$\mathbf{X_2}$ Pendulum Position	$\mathbf{X_3}$ Command Out
Variable Type	Input	Input	Input	Output
ALN Tolerance	0.1	5	0.1	0.01
ALN Weight Max	1,000,000	1,000,000	1,000,000	1,000,000
ALN Weight Min	-1,000,000	-1,000,000	-1,000,000	-1,000,000
ALN Max	5	2,500	200	5
ALN Min	-5	-2,500	-200	-5
Resolution	60 µ	3.6	0.18	0.00488
Units	inches	degrees/second	degrees	volts DC

Table 3: ALN I/O variables.

Training Dataset

The first step in the development process was to create the training dataset representing the control algorithm mapping. The critical control points for the cart position, pendulum position and velocity inputs to the ALN are identified in **Figure 10**. Changes to the slope of the control surfaces occur at each of these points throughout the control space.

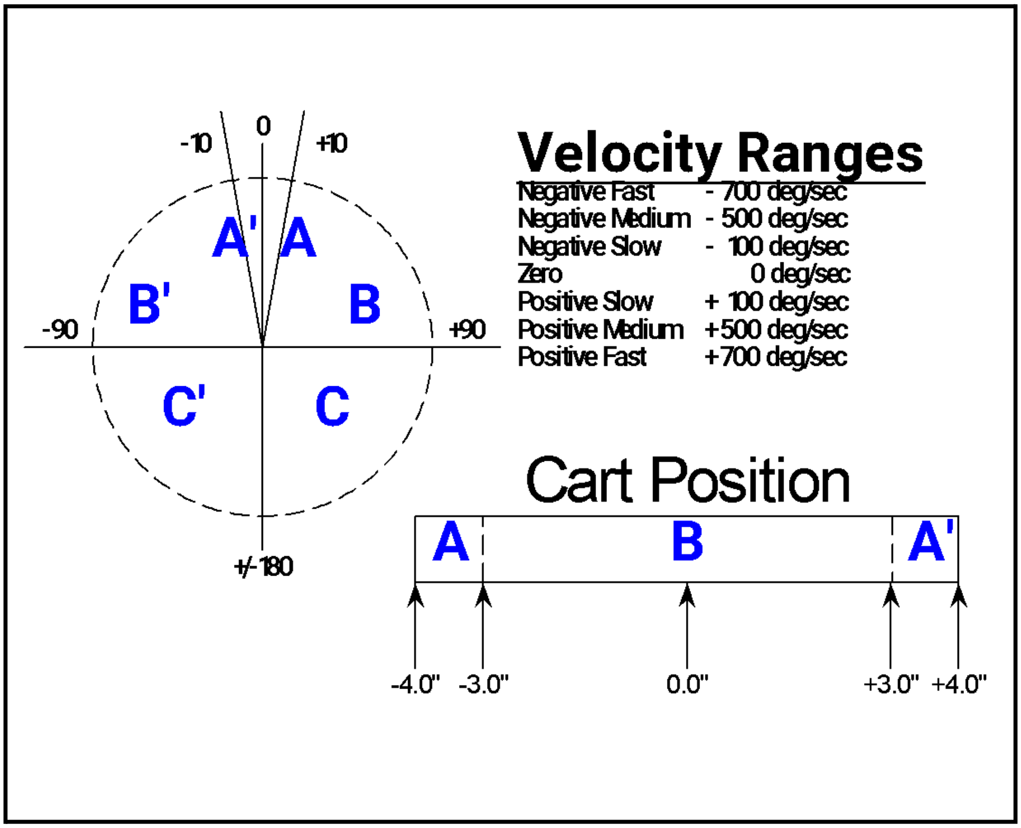


Figure 10: Critical pendulum control points.

Linear Actuator Position	Pendulum		Command
	Position	Velocity	Control Action
A	x	x	Output maximum right (+5.0 volts).
B	A,A' B,B' C,C'	- Fast	See **Figure 15**
		- Medium	
		- Slow	
	Zero	Zero	See **Figure 14**
	A,A' B,B' C,C'	+ Fast	See **Figure 16**
		+ Medium	
		+ Slow	
A'	X	x	Output maximum left (-5.0 volts).

Table 4: Control values summary table.

Control Surface 3-Dimensional Charts

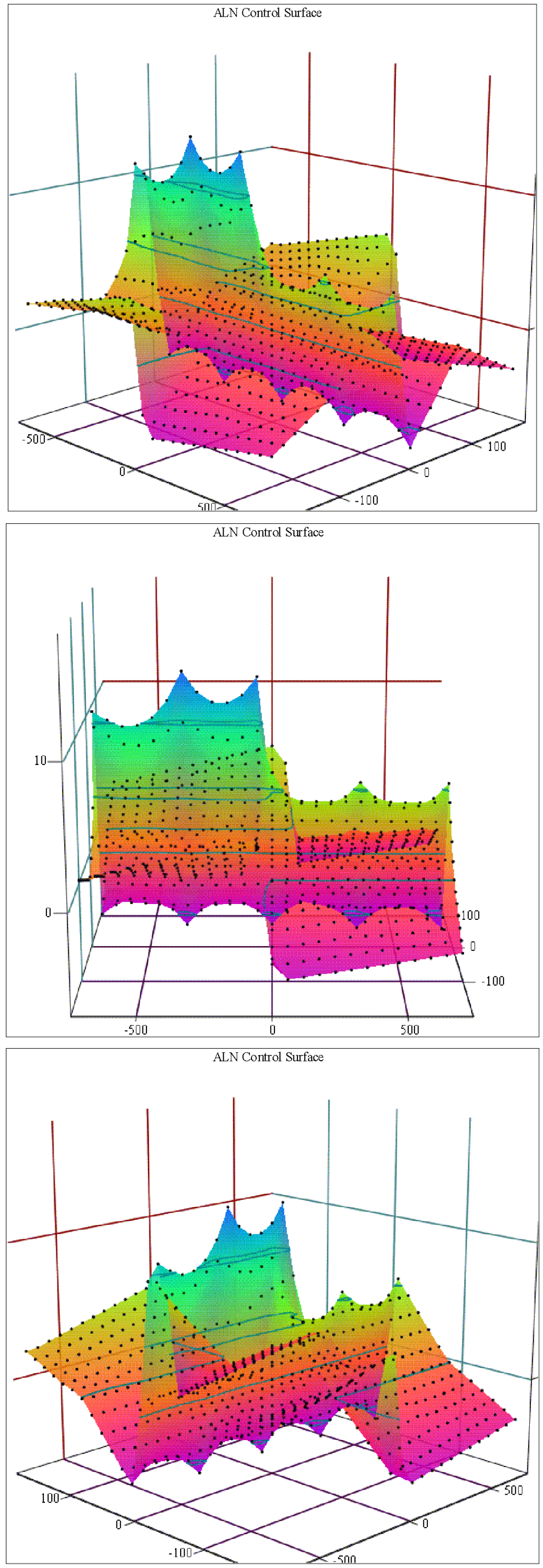


Figure 11: Control Surface 3-Dimensional Charts (3 of 3)

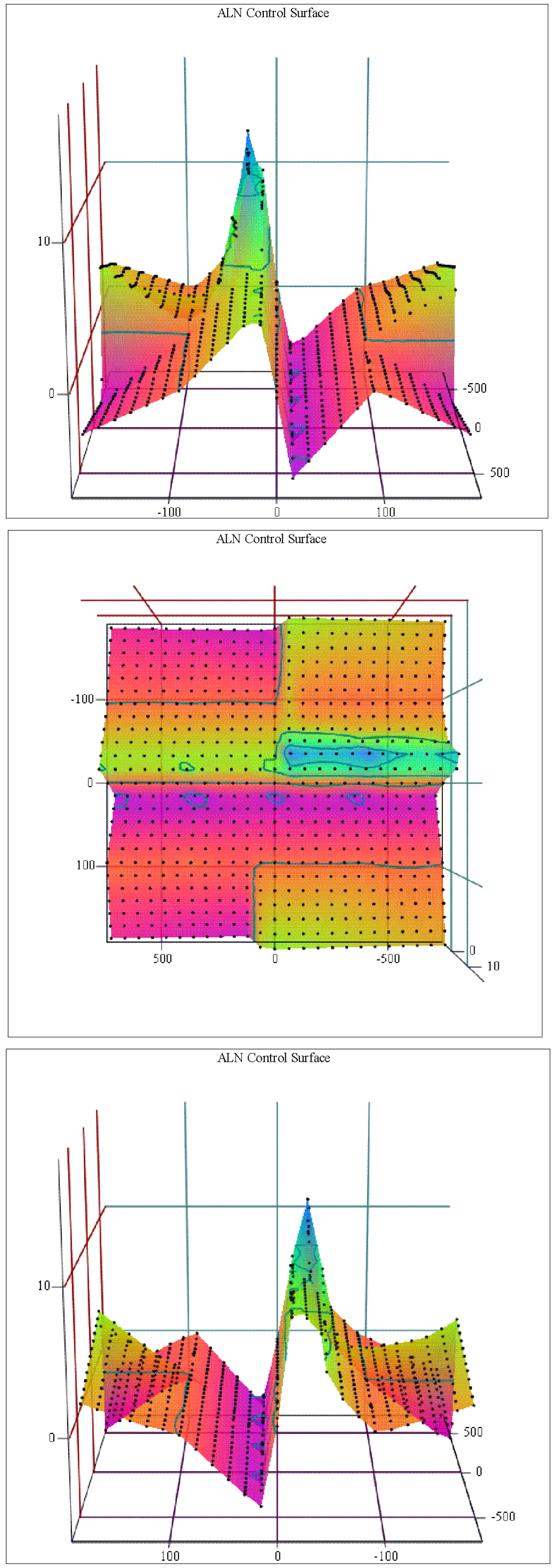


Figure 12: Control Surface 3-Dimensional Charts (2 of 3)

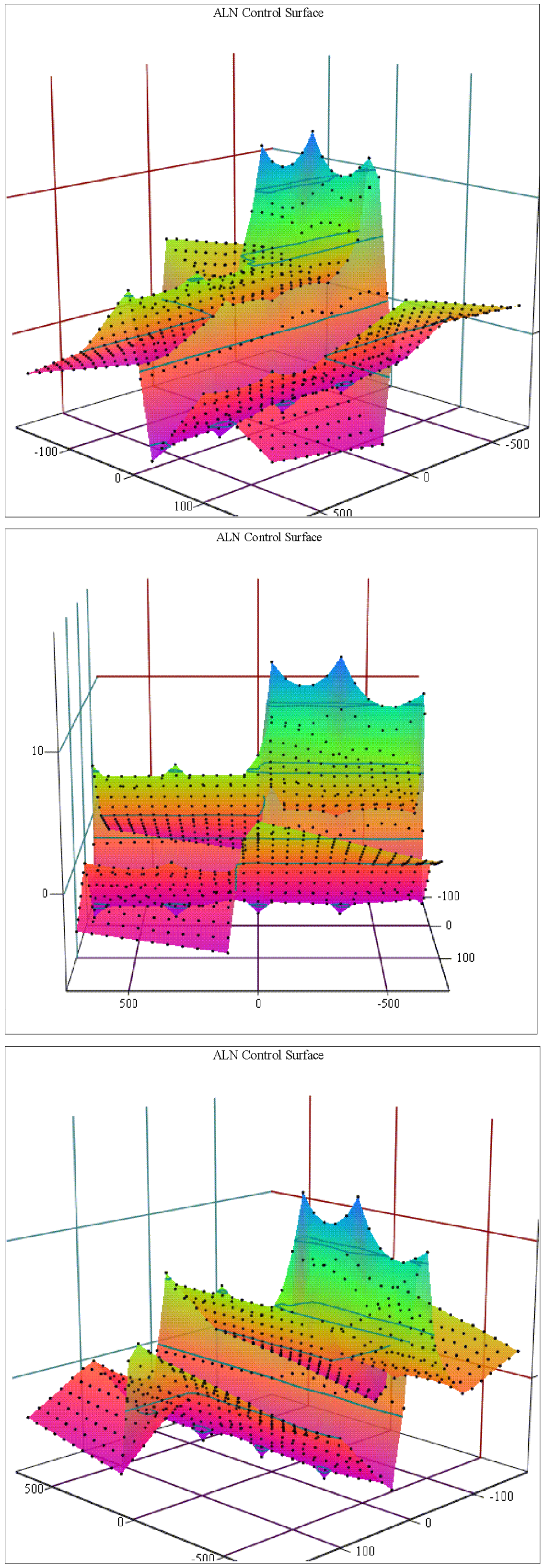
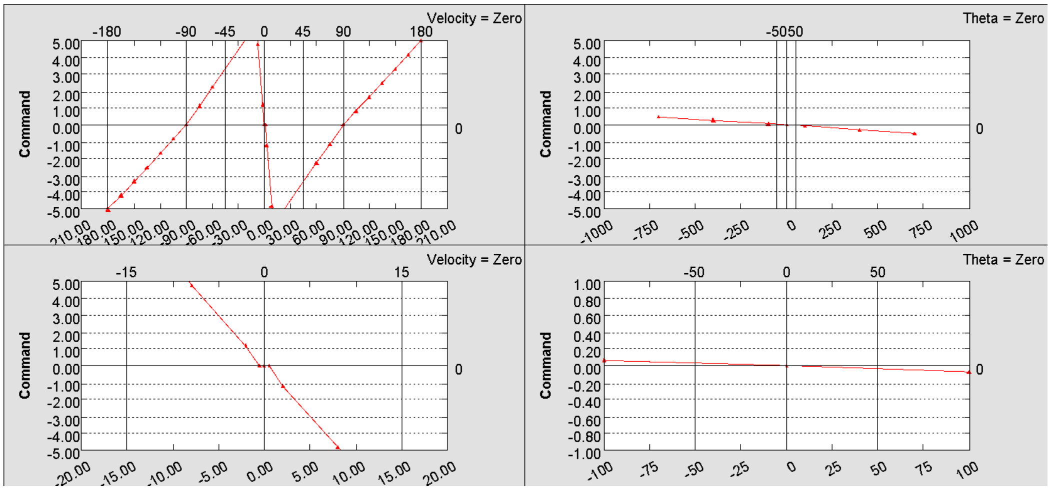


Figure 13: Control Surface 3-Dimensional Charts (3 of 3)



Control Surface Cross-sectional Charts

Figure 14: Control at velocity = zero and theta = zero.

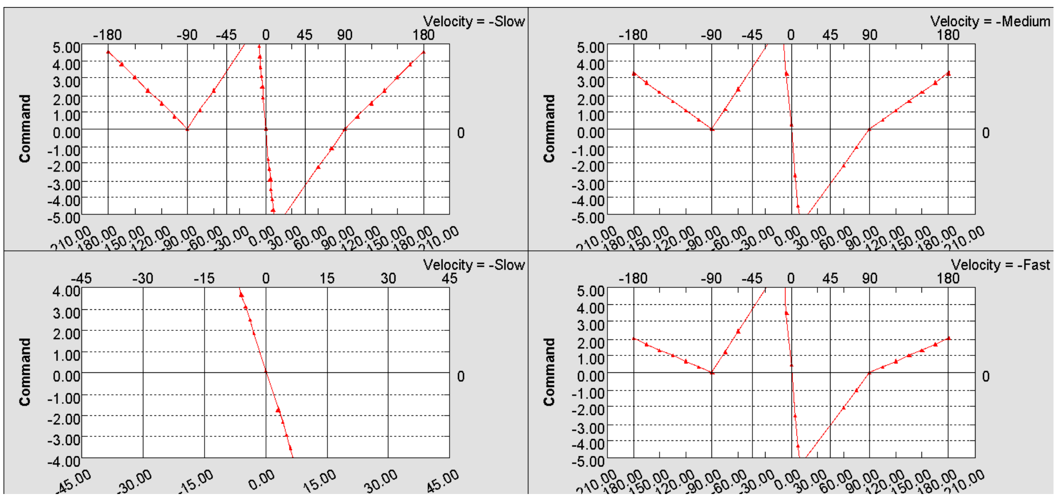


Figure 15: Control at velocity = negative slow, medium and fast.

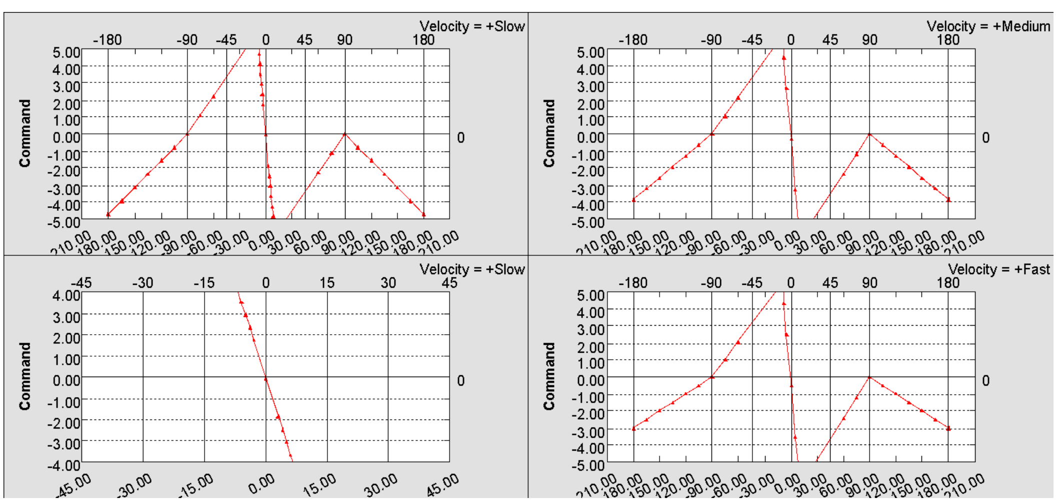
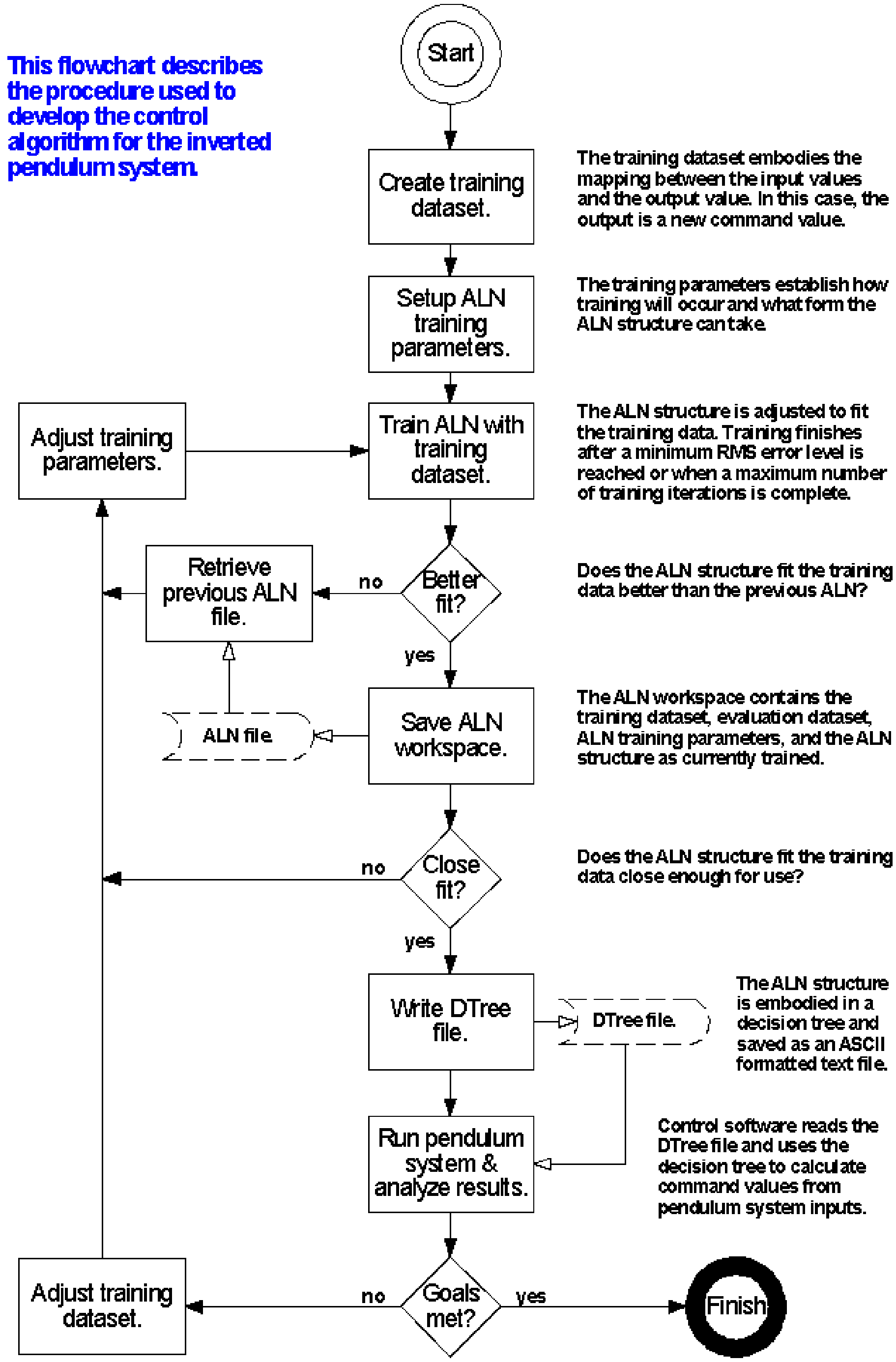


Figure 16: Control at velocity = positive slow, medium and fast.

Control Algorithm Development Procedure

Figure 17: Control algorithm development procedure.



DESCRIPTION OF THE MEASURES EMPLOYED

The control software assumes that the inverted pendulum apparatus is in a specific state when it is started. The pendulum must be in the non-inverted position (theta = +/- 180 degrees), and the linear actuator (i.e. cart) must be centered in the middle of its travel. The apparatus can be operated in automatic or manual mode based on the position of a toggle switch on the front panel. The control software is started with the apparatus in manual mode where the control signal applied to the servomotor is derived from a potentiometer on the front panel. Once the software is running through its normal operating sequence, the toggle switch is moved into the automatic position, resulting in the analog command signal from the DAQ board being applied to the servomotor. See **Figure 18** for an overview of the software operation.

Figure 18: Control software execution sequence.