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Control in a MATLAB® Environment

Digital Pendulum

Control Experiments

33-936-1V65

**(For use with MATLAB 6.5 version
and Windows 95, 98, NT,2000)**



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Notes



DIGITAL PENDULUM CONTROL EXPERIMENTS

Preface

THE HEALTH AND SAFETY AT WORK ACT 1974

We are required under the Health and Safety at Work Act 1974, to make available to users of this equipment certain information regarding its safe use.

The equipment, when used in normal or prescribed applications within the parameters set for its mechanical and electrical performance, should not cause any danger or hazard to health or safety if normal engineering practices are observed and they are used in accordance with the instructions supplied.

If, in specific cases, circumstances exist in which a potential hazard may be brought about by careless or improper use, these will be pointed out and the necessary precautions emphasised.

While we provide the fullest possible user information relating to the proper use of this equipment, if there is any doubt whatsoever about any aspect, the user should contact the Product Safety Officer at Feedback Instruments Limited, Crowborough.

This equipment should not be used by inexperienced users unless they are under supervision.

We are required by European Directives to indicate on our equipment panels certain areas and warnings that require attention by the user. These have been indicated in the specified way by yellow labels with black printing, the meaning of any labels that may be fixed to the instrument are shown below:



CAUTION -
RISK OF
DANGER



CAUTION -
RISK OF
ELECTRIC SHOCK



CAUTION -
ELECTROSTATIC
SENSITIVE DEVICE

Refer to accompanying documents

PRODUCT IMPROVEMENTS

We maintain a policy of continuous product improvement by incorporating the latest developments and components into our equipment, even up to the time of dispatch.

All major changes are incorporated into up-dated editions of our manuals and this manual was believed to be correct at the time of printing. However, some product changes which do not affect the instructional capability of the equipment, may not be included until it is necessary to incorporate other significant changes.

COMPONENT REPLACEMENT

Where components are of a 'Safety Critical' nature, i.e. all components involved with the supply or carrying of voltages at supply potential or higher, these must be replaced with components of equal international safety approval in order to maintain full equipment safety.

In order to maintain compliance with international directives, all replacement components should be identical to those originally supplied.

Any component may be ordered direct from Feedback or its agents by quoting the following information:

- | | |
|------------------------|----------------------------|
| 1. Equipment type | 2. Component value |
| 3. Component reference | 4. Equipment serial number |

Components can often be replaced by alternatives available locally, however we cannot therefore guarantee continued performance either to published specification or compliance with international standards.



DECLARATION CONCERNING ELECTROMAGNETIC COMPATIBILITY

Should this equipment be used outside the classroom, laboratory study area or similar such place for which it is designed and sold then Feedback Instruments Ltd hereby states that conformity with the protection requirements of the European Community Electromagnetic Compatibility Directive (89/336/EEC) may be invalidated and could lead to prosecution.

This equipment, when operated in accordance with the supplied documentation, does not cause electromagnetic disturbance outside its immediate electromagnetic environment.

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**DIGITAL PENDULUM
CONTROL EXPERIMENTS**

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1 Introduction

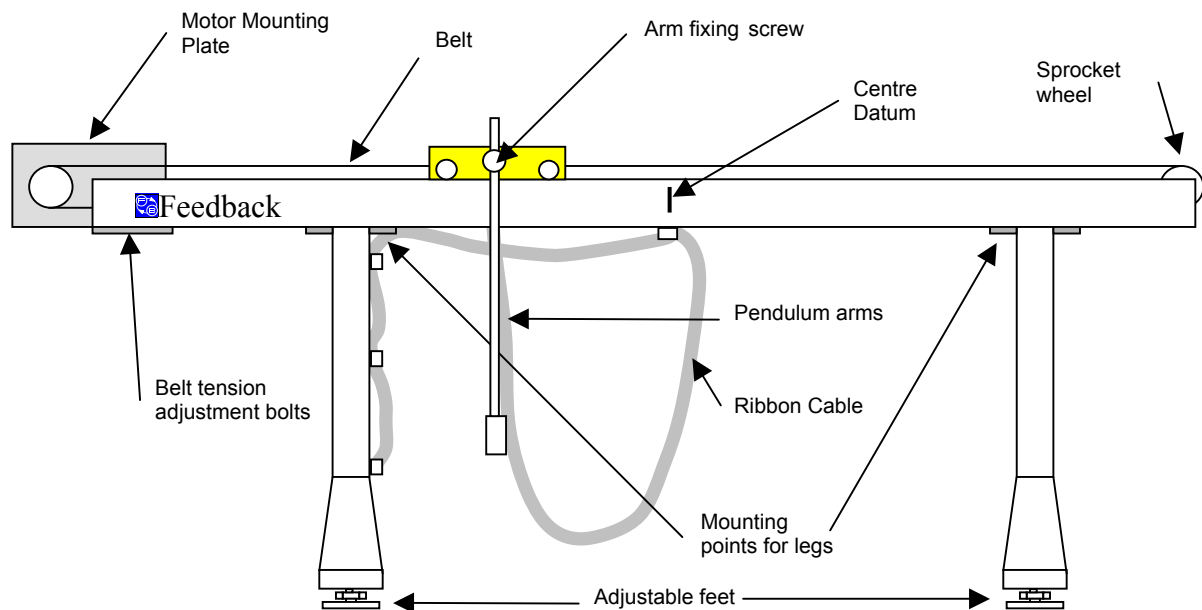


Fig 2.1: The pendulum system

The pendulum system consists of a rail and a cart which can move along it. Attached to the cart are two pendulums which are free to rotate around a horizontal axis attached to the cart

The control objective is to raise the pendulum from a down position to an upright position by moving the cart back and forth along the rail without touching the ends.

When the pendulums are in the upright position then the control objective is to keep them upright vertical and at the same time to be able to move the cart in a predetermined trajectory.

Swinging up the pole may result in over-reaching the upper unstable equilibrium point.

To achieve a “soft” landing in the vicinity of the upright position, a routine called the soft landing arbiter checks whether the kinetic energy of the pole, minus the energy loss due to friction, is sufficient to raise the centre of gravity of the pole to its upright position.



If the condition is satisfied then the control is set to zero and the "bang-bang" character of the control is finished. After the pole has entered the stabilisation zone, the system can be treated as linear and the control is switched to the stabilising algorithm.

As the rail is limited in length, part of the control algorithm requires that a prediction has to be made whether the cart is likely to hit the end stops (or the micro switches which cut power to the motor). If this is the case then sufficient power is applied to the motor in the opposite direction to ensure that the end points of the rail are not reached.

The pendulum is an example of a Multiple Input (pendulum angle and cart position) and Single Output (power to the motor) system.



2 Safety Instructions

Read these instructions carefully



Ensure you are acquainted with the safety Instructions in the Preface to this Manual



Do not enter the workspace of the Equipment whilst it is in operation.



In the event of an emergency, the control effort should immediately be discontinued by hitting the Red Stop button on the Pendulum Control Unit.



All users of this equipment should be familiar with and trained in good Laboratory Practice where electrical machinery is used.



When running any control experiment ensure that the Real Time control program is running before pressing the Start button on the equipment control unit



**DIGITAL PENDULUM
CONTROL EXPERIMENTS**

Chapter 2

Safety Instructions - [Read This](#)

Notes



3 Experiment 1 – Double PID Crane Control

Theory and Model Description

The crane problem is where the pendulum is hanging in the down (equilibrium) position from the cart. Swing is induced in the pendulum as the cart is moved back and forth by the DC motor. Generally, the goal of the crane control problem is to move the cart between positions; preferably as fast as possible, with few oscillations, and without letting the angle and velocity of the pendulum swing become too large or the duration of the swing too prolonged. This problem is named for the similarity to the problem of controlling overhead cranes used at shipping ports and construction sites to move cargo and supplies.

The PID control rule is very common in control systems. It is the basic tool for solving most process control problems. The PID controllers are usually standard building blocks for industrial automation. The most basic PID controller has the form

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt}(e(t))$$

where $u(t)$ is the control output

and the error, $e(t)$, is defined as

$e(t)$ = desired value – measured value of quantity being controlled.

The control gains

K_p , K_d , and K_i

determine the weight of the contribution of the error, the integral of the error, and the derivative of the error to the control output and will dictate the response of the closed-loop system to the initial conditions and inputs.

There are a number of tuning methods for PID controllers. Some of them are based on transient response experiments e.g., the Ziegler-Nichols step response tuning rule, other are based on relay feedback when the parameters of a PID controller are determined from features of the limit cycle of the closed-loop system, some others are based on frequency



Double PID Crane Control

We shall consider the pendulum-cart control system containing two PID controllers. The first operates based on the angle of the pendulum and the second operates based on the position of the cart. The outputs of the PID controllers are added to produce the final control value for the D/A converter, and as a result the output motor torque.

The screenshot shows the Simulink model for the CranePID/Control Subsystem. The diagram includes the following components and connections:

- Inputs:**
 - In1** and **In2** are summed at a junction.
 - In3** and the output of the **pl** (Proportional) block are summed at another junction.
- Controllers:**
 - The first sum junction feeds into the **PID Cart Controller**.
 - The output of the **PID Cart Controller** is summed with **In3** and the **pl** block output at the second sum junction.
 - The second sum junction feeds into the **PID Pendulum Controller**.
- Outputs and Feedback:**
 - The **PID Pendulum Controller** outputs **Voltage**, which is summed with **Out1** and **Out2** at a third sum junction.
 - The output of the third sum junction is **Out2**.
 - Out1** is the **Pendulum Angle Deviation from Equilibrium**.
 - Out2** is the **Cart Velocity**.
- Signal Processing:**
 - The **Pendulum Angle Deviation from Equilibrium** is passed through a **Plot Scaling** block (gain of -1) before being summed with **In1** and **In2**.
 - The **Cart Velocity** is integrated by the **Cart Velocity Filter** block, which has the transfer function $\frac{1e4}{s^2 + 70.7s + 1e4}$.
 - The output of the filter is **derPendPos**, which is the input to the **pl** block.
- Other Elements:**
 - A **Friction Compensation** block (represented by a meter icon) receives **Cart Velocity** and outputs **Out1**.
 - A **Scope** block is connected to the output of the **Friction Compensation** block.

Loading the RTWT Block Diagram

Start MATLAB

CranePID



Double PID Crane Control

Figure 3-2: Simulink Block Diagram for Crane Control Experiment

Simulink Block Diagram - Description of Block Functions

In Figure 3-2, the green blocks denote input/output operations or hardware and the red block denotes the safety subsystem. The user has full access to the control algorithm and safety settings. The control gains should be changed only after their affect on the stability of closed-loop system is understood. The user must read the RTWT User's Manual in great detail before modifying the hardware and safety blocks.

Input Output Setup

In Figure 3-2, the green blocks, labeled “Read Cart Encoder” and “Read Pendulum Encoder”, represent the input of the cart and pendulum positions as encoder counts from two incremental encoders.



DIGITAL PENDULUM CONTROL EXPERIMENTS

Experiment 1

Double PID Crane Control

Note

Prior to the start of a control experiment the system must be at the reference position. This may entail the user depressing the “STOP” button and manually moving the cart to the center of travel and manually stabilizing the pendulum in the down position.

These cart and pendulum positions will be referred to as 0 meter and π radian, respectively. Motion of the cart to the right from the reference position will be considered motion in the positive direction and clockwise rotation of the pendulum will be considered positive.

The input blocks and the attached scaling blocks must be configured so that the startup initializes these positions and the feedback has the correct direction sense

Read Cart Encoder Block

Block Parameters: Read Cart Encoder

Feedback Encoder Block (mask) (link)

Special block to use with the Feedback experiments to read encoder channels using the digital I/O lines

Parameters

Channel (0 or 1)

0

Encoder Offset

0

sample Time (sec)

0.001

☒ Access Hardware

OK Cancel Help Apply

Figure 3-3: Cart encoder input configuration dialogue box



Double click on the “Read Cart Encoder” to open the dialog box shown in Figure 3-3.

There are three edit windows for entering

Channel

Sampling Time

Encoder Offset

You will notice that there are preset values already entered into the four edit windows.

Note

The Advantech PCI1711 PCI I/O card has its base address automatically set by Windows, and it is therefore not necessary for the user to set it.

In the following experiments the following values are set

Encoder Channel is set to 0

Sampling Time is set to 0.001

Encoder Offset is set to 0 to initialize the cart encoder input to zero encoder counts at the start of the simulation, thus naming the start position zero.

Note that the **Access Hardware** is enabled.

The scaling block converts from counts of the incremental encoder turning with the motor, to units of meters for the movement of the cart along the rails.



Read Pendulum Encoder Block

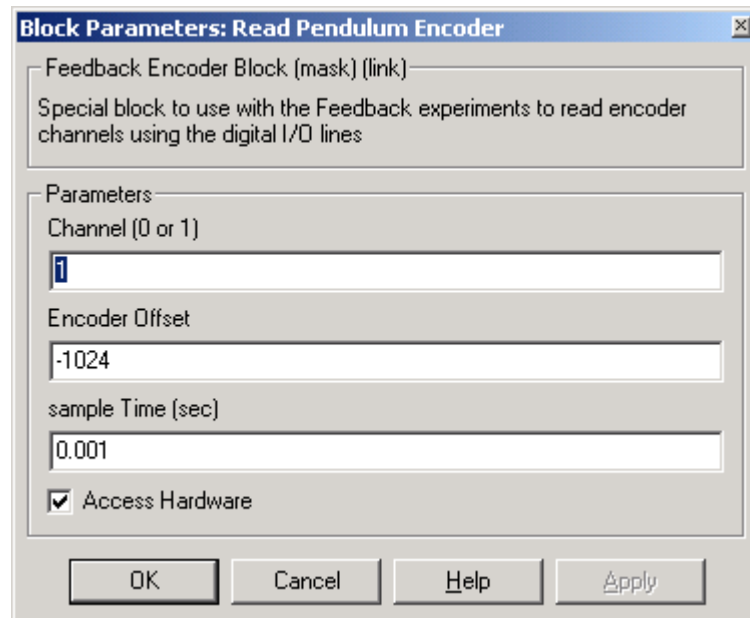


Figure 3-4: Pendulum encoder input configuration dialogue box

Double click on the “Read Pendulum Encoder” to open the dialog box shown in Figure 3-4.

In the following experiments the following values are set

Encoder **Channel** is set to 1

Sampling Time is set to 0.001

Encoder Offset is set to -1024. This sets the pendulum reference position to π according to the following calculation.

$$\begin{aligned}\text{Reference Position} &= -1024 \text{ count} \times \frac{1 \text{ pendulum revolution}}{2048 \text{ count}} \times \frac{-2\pi \text{ radian}}{1 \text{ pendulum revolution}} \\ &= \pi \text{ radian}\end{aligned}$$

where the -2π term is contributed by the scaling block. The sign on the scaling blocks create the proper direction sense as described above.

Note that the **Access Hardware** is enabled.



**Digital to Analogue
Converter Block**

The output command must match the capabilities of the hardware.

The Advantech board is capable of outputting a 0-5V signal. This signal is shifted in the amplifier to create a $\pm 2.5V$ capability required to command the drive motor in both directions. The shifting is transparent to the user at this level of use, so it is only necessary to ensure that the output command is in the range $\pm 2.5V$.

The saturation block found in “Scaling and Safety” ensures that this constraint is met. Scaling is set to 1 so that a positive input creates motor torque that acts to move the cart in the positive direction.

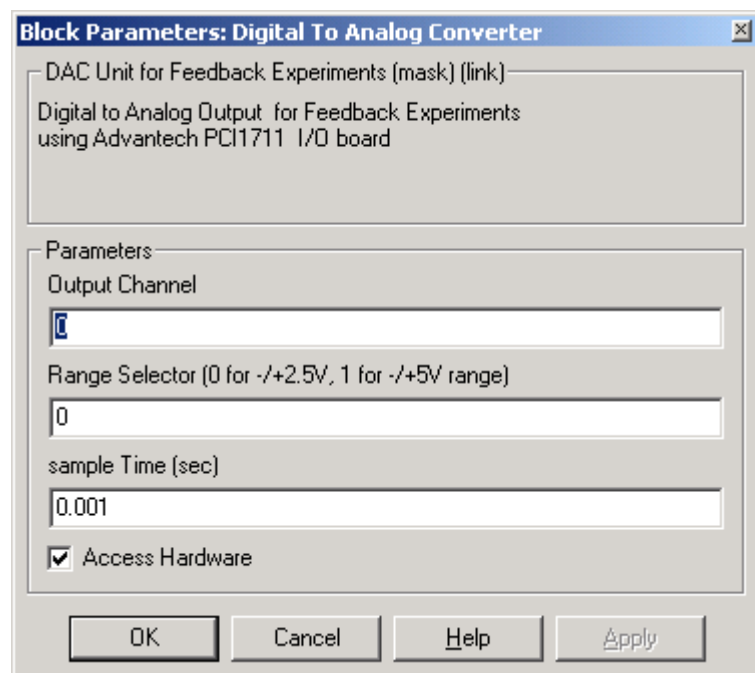


Figure 3-5: Digital to Analogue converter configuration dialogue box

Double click on the “Digital to Analogue Converter Block” to open the dialog box shown in Figure 3-5.



Double PID Crane Control

Sample Time is set to 0.001

Double click on this block to open the PID control subsystem shown in Figure 3-6.

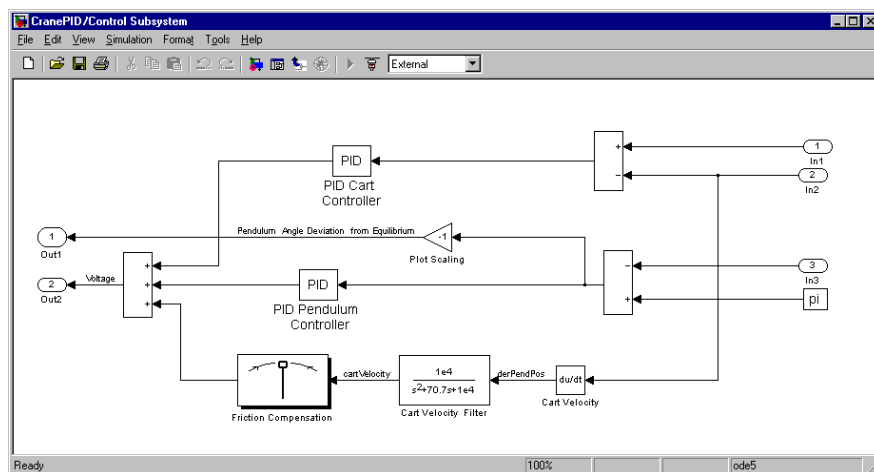


Figure 3-6: Crane mode PID subsystem

To reveal the structure either right click the mouse and select "Look under mask" or type (Ctrl+u) as shown in Figure 3-7 and Figure 3-8.



DIGITAL PENDULUM CONTROL EXPERIMENTS

Experiment 1

Double PID Crane Control

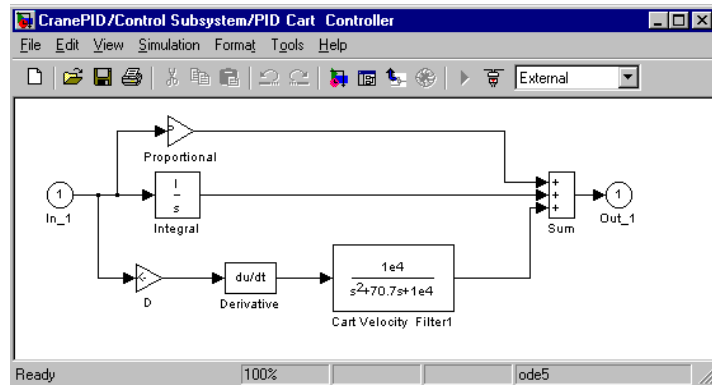


Figure 3-7: PID Cart Controller

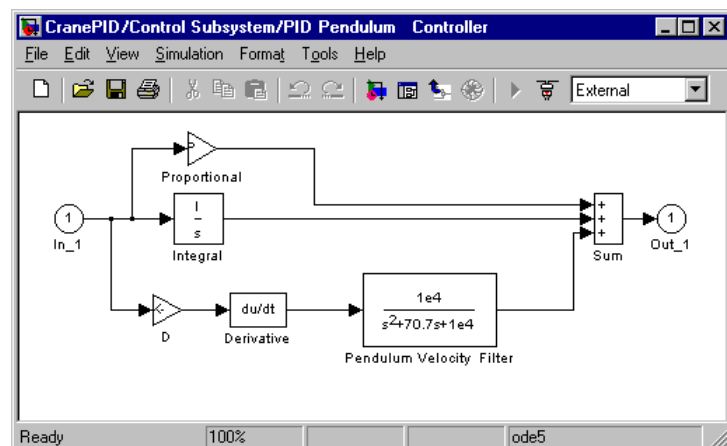


Figure 3-8: PID Pendulum Controller

Double click on these same blocks to reveal the changeable control gains as shown in Figure 3-9 and Figure 3-10.

Block Parameters: PID Cart Controller

PID Controller (mask)

Enter expressions for proportional, integral, and derivative terms.
 $P+I/s+Ds$

Parameters

Proportional:
10

Integral:
1

Derivative:
2

OK Cancel Help Apply

Figure 3-9: PID Cart Controller Parameters

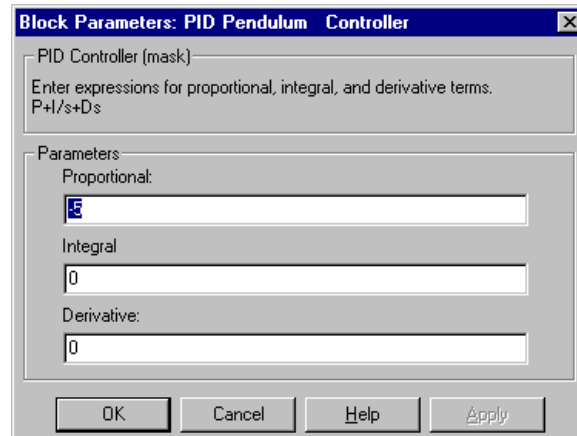


Figure 3-10: PID Pendulum Controller Parameters

Friction

An addition block “Friction Compensation” is used to compensate for the nonlinear static friction.

The diagram in Figure 3-11 represents the experimental relationship between cart friction and cart velocity.

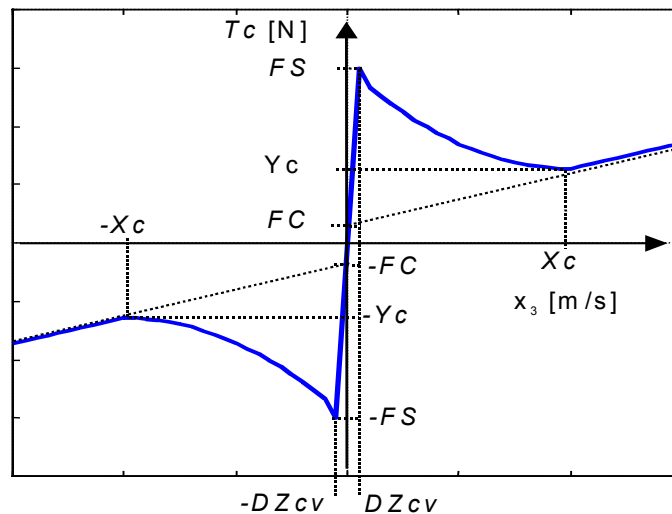


Figure 3-11: Typical cart friction T_c versus cart velocity x_3

Static friction exists in the dead zone of the cart, and this requires force to be applied on order to start movement ($0 < \text{cart velocity} < DZ_{cv}$).

Having overcome this initial friction, however, the static friction reduces, with an approximately quadratic relation to velocity, but the dynamic friction increases almost linearly with velocity.



The static friction eventually reaches a constant value of zero (at cart velocity = x_c), at which point the total friction becomes equal to the dynamic or Coulomb friction.

Since friction always acts in a direction opposite to the direction of motion, the function is mirrored for negative values of cart velocity with the friction force changed in sign.

The compensation used here represents a simplified approach in which the cart velocity is used to indicate the direction of a constant force offset.

The output of this function shown in Figure 3-13 produces a force in the direction of the sign of the velocity. It is clear that this can only partially compensate for the actual friction shown in Figure 3-11.

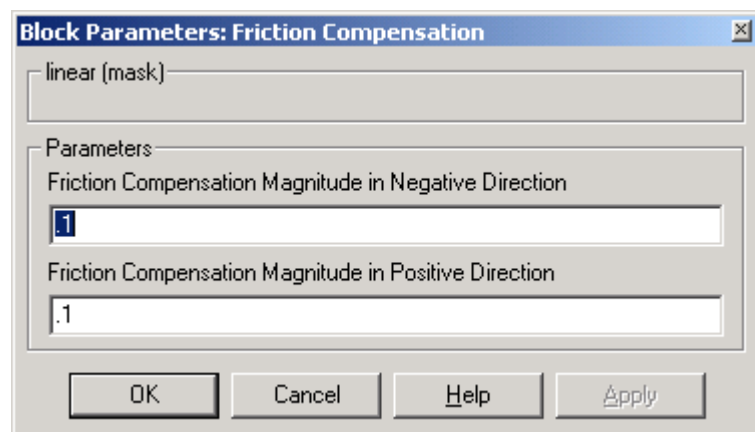


Figure 3-12: Friction Block parameters

The magnitude of the constant offset was obtained though applying the friction compensation as the only output (achieved by setting all PID gains for the cart and pendulum to zero) then varying the magnitude through trial and error until it feels that the cart glides freely. The user may adjust this magnitude slightly in order to better match the friction in a given system (Figure 3-12)

The user should continue through this manual and run the defined experiments before attempting to adjust the friction in this manner.

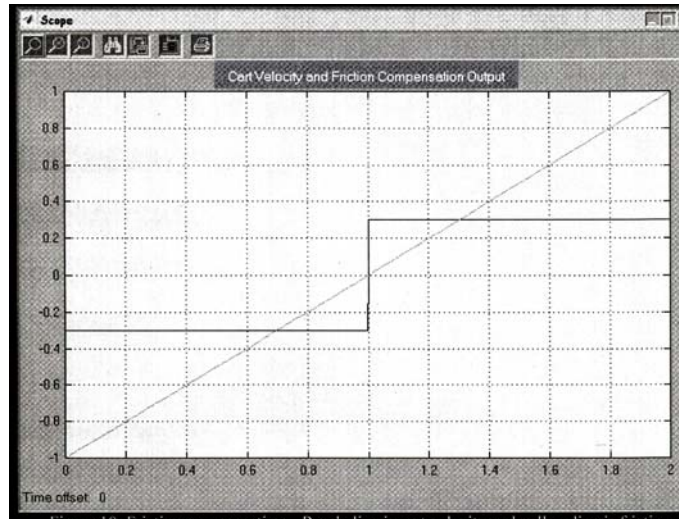


Figure 3-13: Friction Compensation

Display

The purple “Scope” block in Figure 3-2 provides the user with a record of the system states. This window can be opened, by double-clicking on the block *before* running the control, in order to see a live display. It can also be opened *after* the control has stopped in order to see a plot of systems states.

The user is referred to Simulink help for the options to scale, zoom, and print using this standard scope block.

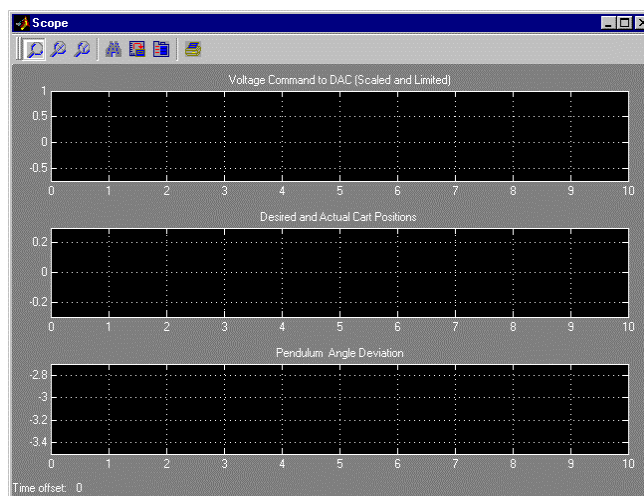


Figure 3-14: Scope Block



Building the Model

Build Options

Before initiating the subsequent automatic build process (that is using Real Time Workshop to generate, compile and link the actual C code to run the control model), it is necessary to ensure that the build options are set correctly.

To this end, select **Tools** from the Simulink model menu bar and then selecting **Real-Time Workshop** followed by **Options** from the pull-down menu. The **Simulation Parameters** window appears as shown in Figure 3-15.

From this window, click on the **Real-Time Workshop** tab as shown in Figure 3-15.

If you have followed the installation sequence described in both this manual and the introductory manual 33-000-1 the Simulation Parameters window should look exactly as in Figure 3-15.

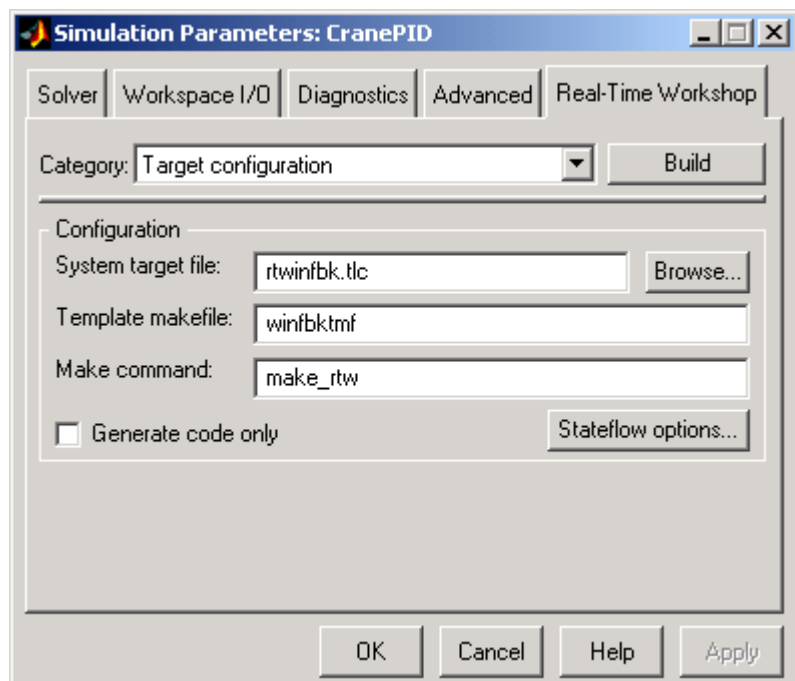


Figure 3-15: Simulation Parameter Options



DIGITAL PENDULUM CONTROL EXPERIMENTS

Experiment 1

Double PID Crane Control

Non standard

Installations

If the text in the

System target file

Template makefile

Make command

edit boxes is not the same as shown in Figure 3-15 then follow the following sequence

Click on the **Browse** button.

From the resulting **System Target File Browser** window, select

rtwinfbk.tlc RTWT Extensions for Feedback
Experiments

as shown in Figure 3-16.

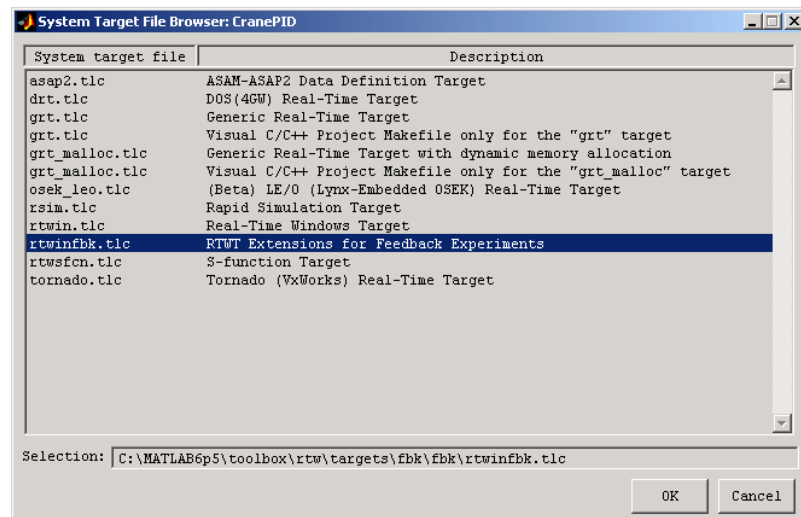


Figure 3-16: System Target File Browser

When the Simulation Parameters window is correctly set up, click the **Build** tab.

Real Time Workshop will now generate, compile and link the code necessary to run the model.



After selecting **Real-Time Workshop / Build** for *feedbackCraneDPID.mdl*, the following files will be automatically generated and saved in the directory *c:\Feedback\Pendulum*

feedbackCraneDPID.bat, feedbackCraneDPID.c,
feedbackCraneDPID.dt,

feedbackCraneDPID.h, feedbackCraneDPID.mk,
feedbackCraneDPID.obj,

feedbackCraneDPID.prm, feedbackCraneDPID.reg,
feedbackCraneDPID.rwd.

To connect to the target and execute the control program, follow the following sequence

Select **Tools** from the Simulink model menu bar.

Select **External Mode Control Panel** from the pull-down menu. The window shown in Figure 3-17 appears.

Click on the **Connect** button.

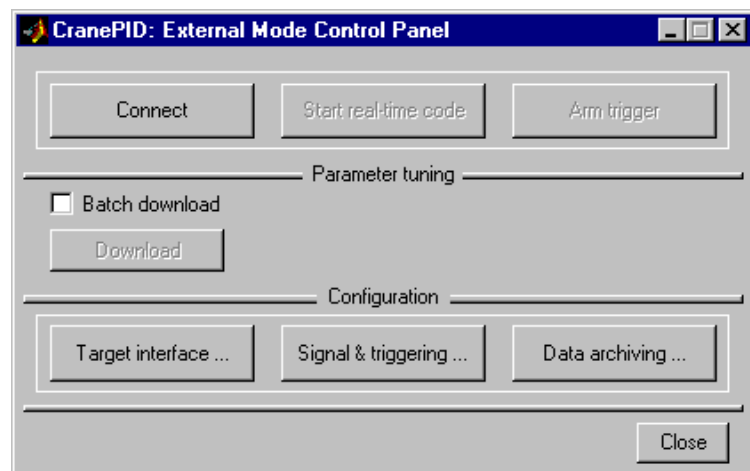


Figure 3-17: External Mode Control Panel

The **Connect** Button changes to **Disconnect** and the **Start real-time code** button is made available.

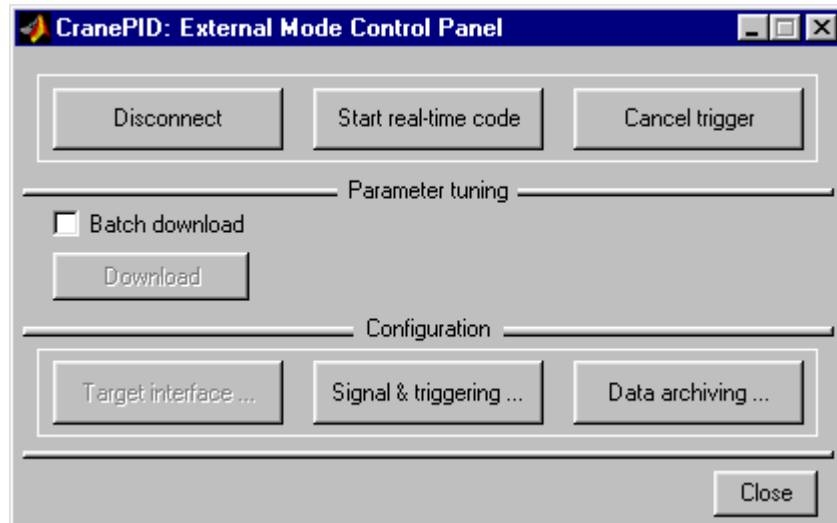


Figure 3-18: External Mode Control Panel

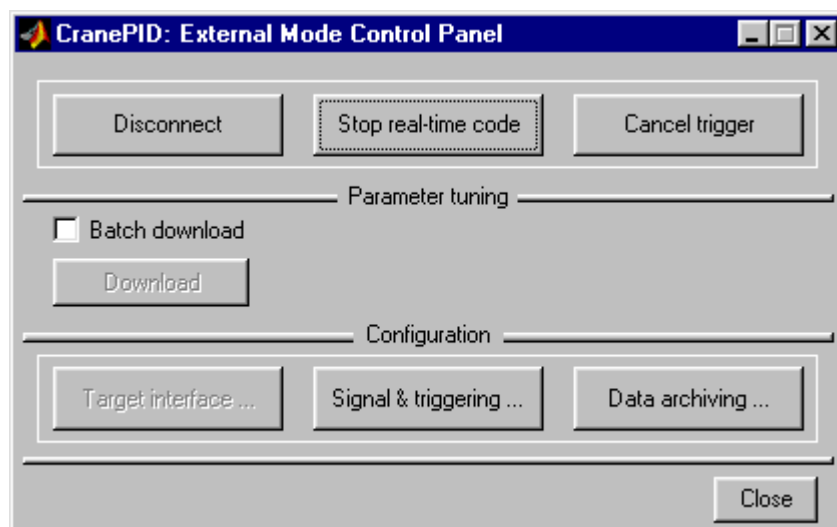


Figure 3-19: External Mode Control Panel

Note

The reference position is established during connection to the real-time target; thus the system must be moved to the reference position *before* the Connect button is activated.

If the system is not at the reference position, indicated by a vertical bar label on the cart track, click on the Disconnect button, move the cart to the reference position, and click on the Connect button.



DIGITAL PENDULUM CONTROL EXPERIMENTS

Experiment 1

Double PID Crane Control

Control Program Execution

Starting

To **begin** execution of the real time Control Program, click the

`Start real-time code button`

The control software is now active (the Advantech hardware adapter has been started)

Press the **Green** Start button on the pendulum control unit

Stopping

To **stop** execution of the real-time target click either the

`Stop real-time code button` or the
`Disconnect button` shown in Figure 3-19.

Press the **Red** Stop button on the pendulum control unit

In the `External Mode Control Panel`, the check box

`batch download`

under the

`Parameter tuning`

group title, controls the behaviour of the parameter tuning. If the

`batch download`

check box is enabled, then the new parameters will not be downloaded automatically to the real-time target until you click the

`Download`

button .

This feature is useful in a situation where you need to change *multiple* parameters and desire that all of these changes take effect instantaneously. Note, however, that there are some limitations to this capability.



DIGITAL PENDULUM CONTROL EXPERIMENTS

Experiment 1

Double PID Crane Control

Changing Real Time Parameters

To change parameters follow the following sequence;

Double Click the Simulink Block containing the parameters, make the changes, and then click the `Apply` Button followed by `OK`.

Note

Some of the parameters can be changed during program execution, others dealing with *changes* to the model will necessitate a new system build and new c code generation.

Real Time Workshop will inform you if a new build is necessary.

For example, the P I and D coefficients values can be changed in real time without re-compilation as they are simply constants read by the real time program, whereas a change of the exciting waveform from square to sinusoidal, will require a new-build.

System Operation

Before starting any experiments, perform the following steps:

Make sure that the green *Start* button on the controller box is in its **off** position. (not lit)

Switch-on the *power* switch on the controller box

Bring the cart to the centre of the rail and stop oscillations of the pole.

Start the controlling software as described above (e.g. the Simulink simulation) for an experiment.

Press the green button motor start switch on the controller box



Typical results

Figure 3-20 shows the graph of the cart velocity and friction compensation output. The line with the step function is the friction compensation added to the control based on the velocity, and the continuous line represents the cart velocity.

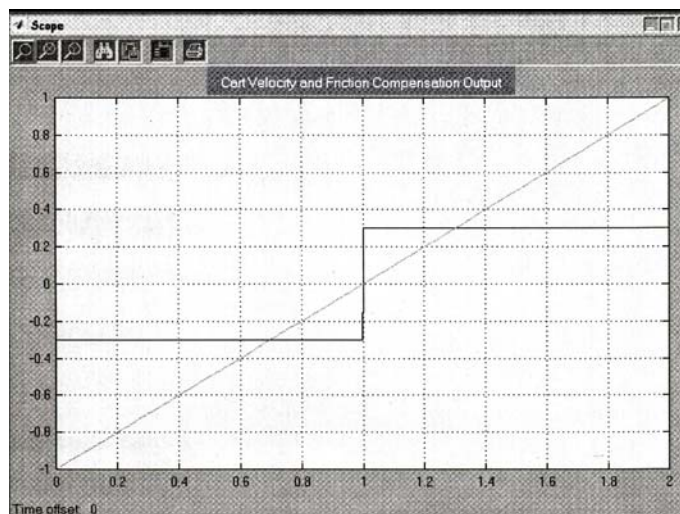


Figure 3-20: Cart friction versus velocity chart

Note that if the friction compensation parameters are set too high, then the cart velocity will be higher than expected leading to possible oscillations of the cart about the desired position.



Figure 16: Double PID crane controller results.

Figure 3-21



The first trial, plotted in Figure 3-21, moves the cart between two points and attempts to reduce the swing of the pendulum at these points.

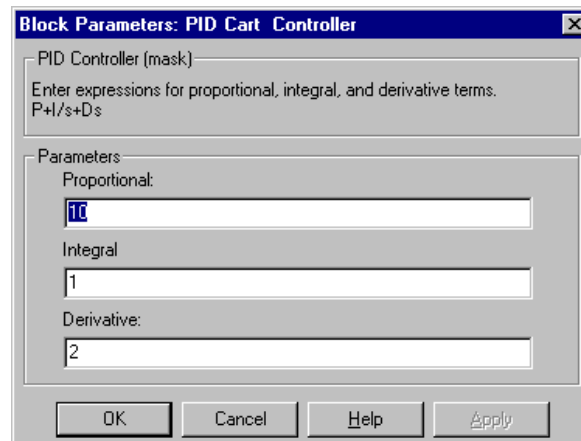


Figure 3-22: PID Cart Controller Gains

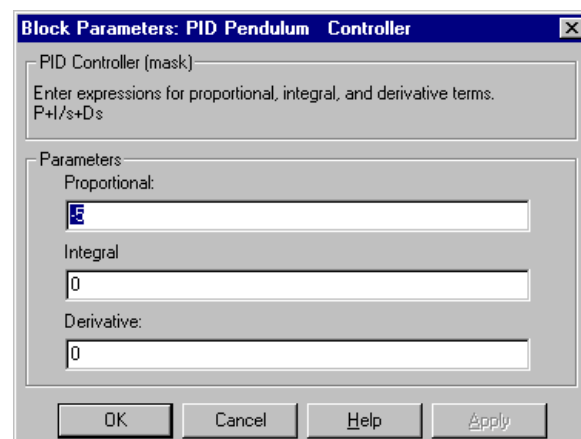


Figure 3-23: PID Pendulum Controller Gains

The gains are shown in Figure 3-22 and Figure 3-23. The effectiveness of the control is highlighted by setting all gains shown in Figure 3-23 to zero in the PID Pendulum Controller” to yield the results shown in Figure 3-24.



Figure 3-24

It can be seen that the cart is following the desired trajectory but that the pendulum continuously oscillates about the equilibrium point.



**DIGITAL PENDULUM
CONTROL EXPERIMENTS**

Experiment 1

Double PID Crane Control

Notes





The goal of this controller is to first move the pendulum near enough to a vertical region, see Figure 4-2, that a PD control can be switched in to stabilize the pendulum in the inverted position.

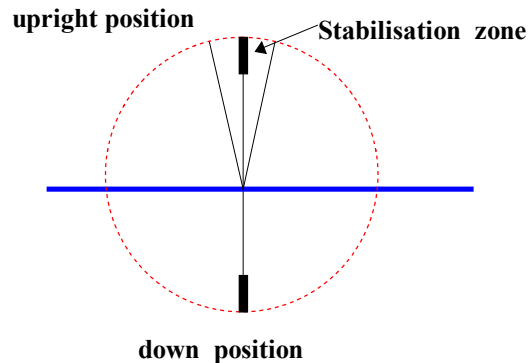


Figure 4-2: Upper Stabilisation Zone

Double Click on the Blue Control System Block in Figure 4-1 to reveal the detail shown in Figure 4-3

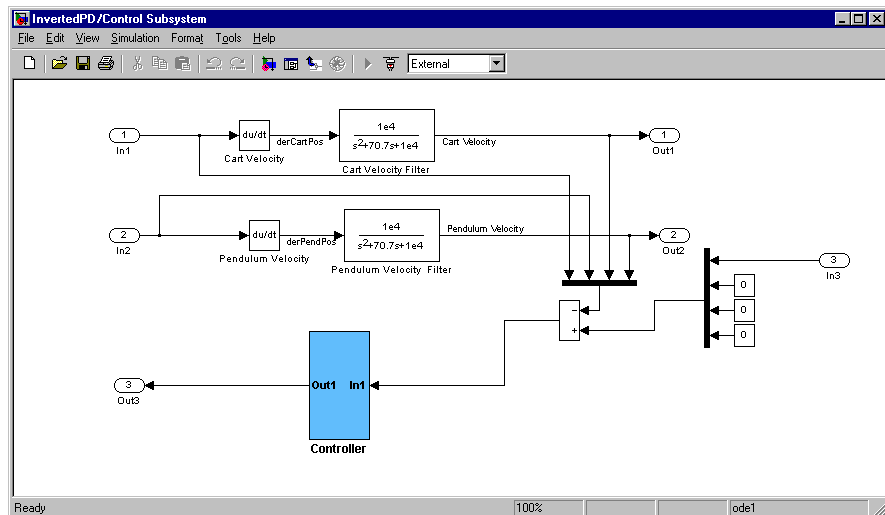


Figure 4-3

Out 1 and Out 2 are outputs to the Simulink scope for cart and pendulum velocity. Out 3 is the control output to the motor.

Double click on the blue Controller block in Figure 4-3 to reveal the details of the controllers, shown in Figure 4-4.



DIGITAL PENDULUM CONTROL EXPERIMENTS

Experiment 2 Inverted Pendulum Swing up and Stabilise

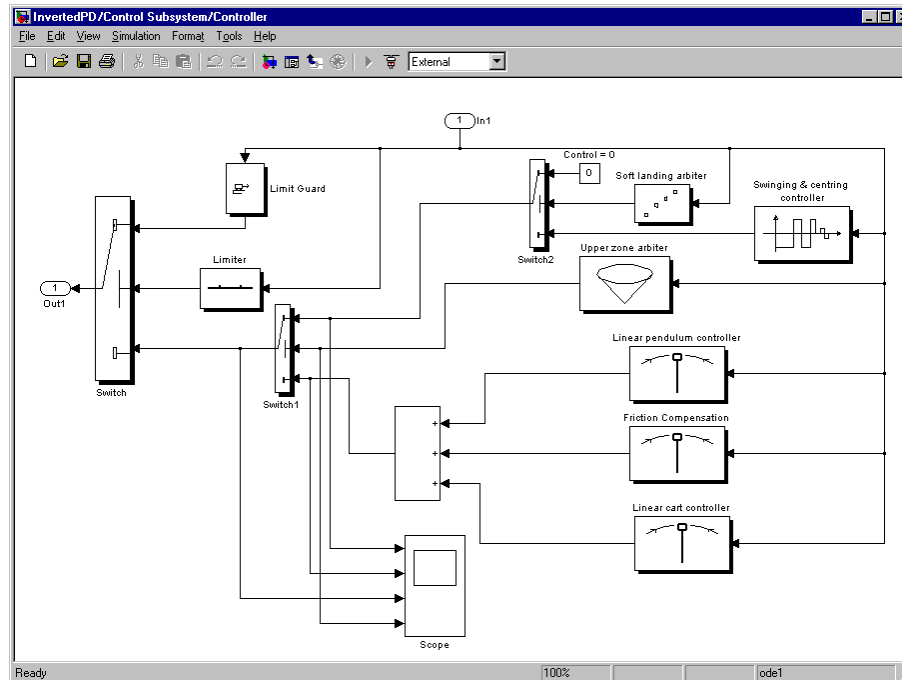


Figure 4-4: Inverted Pendulum Controllers

The block “Upper Zone Arbiter” determines the point at which the stabilizing control is activated.

The "Soft Landing Arbiter" calculates the kinetic energy KE of the pendulum at the lowest vertical point of travel, and the potential energy PE at the highest vertical point of travel. If KE is greater than PE then the pendulum will rotate *through* the vertical point. The function of this block is to limit the swing so that the kinetic energy of the pendulum when entering the stabilisation zone is almost zero.

The “Limiter” block switches the control to a safe mode that moves the cart in the direction away from a travel limit if the cart position approaches either end of travel.

Between these zones the “Swinging Controller” will move the cart in a manner such that the pendulum rotates near the equilibrium position.

The input, output, and friction compensation procedures are identical to the first experiment. The control gains are shown in Figure 4-6 to Figure 4-8.



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Experiment 2 Inverted Pendulum Swing up and Stabilise

The experiment is very sensitive to the values in Figure 4-6; that is, if alpha and beta are too small the cart will run into the overtravel as it attempts to swing up and if they are too large the pendulum will not rotate to within the stabilization zone. The difference between “too large” and “too small” is very little and you may need to make slight adjustments for a given electromechanical system.

The result of this control is shown in Figure 4-5 where it can be seen from the third plot that the pendulum is rotated until it can be stabilized near the zero position (vertical). A cart disturbance is added after the pendulum has balanced as shown in the first plot of Figure 4-5.

Note that the input-output setup, implementation, and execution are the same for both Control Experiments 1 and 2; hence, these topics are not discussed again in this section.



Figure 4-5: Results of Swing up and stabilisation control



Block Parameters: Swinging & centring controller

swing (mask)
swing

Parameters

maximal control umax
1

ALPHA - centering cart factor related to position
2.2

BETA - centering cart factor related to velocity
.4

GAMMA - centering cart factor related to + - pi/2 angle
0.

OK Cancel Help Apply

Figure 4-6: Parameters to control swing behaviour

Block Parameters: Linear cart controller

linear (mask)

Parameters

K1 - position feedback
-7

K3 - velocity feedback
-4

OK Cancel Help Apply

Figure 4-7: Cart PD gains

Block Parameters: Linear pendulum controller

linear (mask)

Parameters

K2 - angle feedback
50

K4 - angular velocity feedback
3.5

OK Cancel Help Apply

Figure 4-8



**DIGITAL PENDULUM
CONTROL EXPERIMENTS**

**Experiment 2
Inverted Pendulum
Swing up and Stabilise**

Notes



5 Experiment 3 - UpDownDemo

This experiment combines both the CranePID and the InvertedPd control experiments, by switching between them on a periodic basis.

Start MATLAB

Type the following command into the MATLAB command window

```
UpDownDemo
```

The Simulink block diagram for the UpDownDemo, appears and is shown in Figure 5-1.

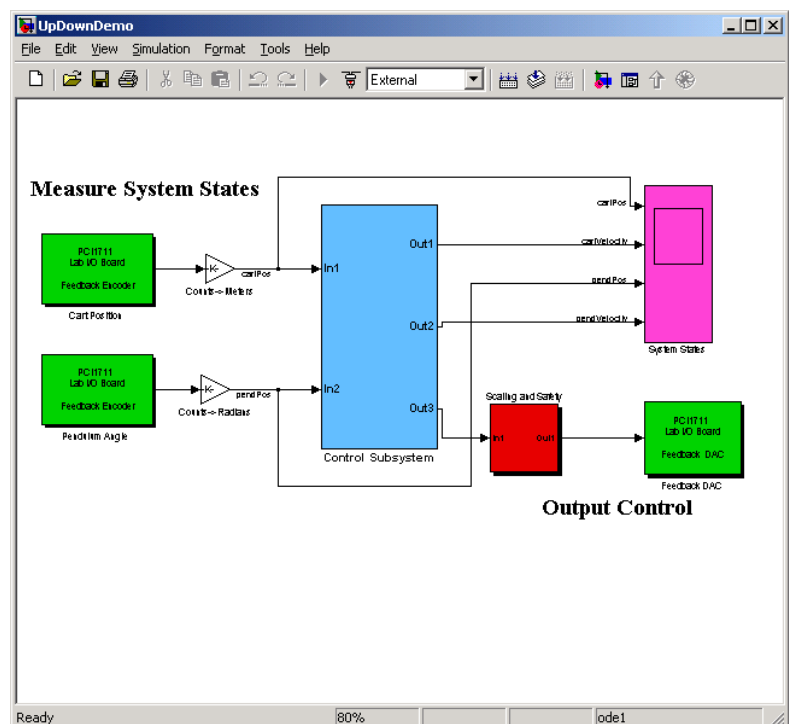


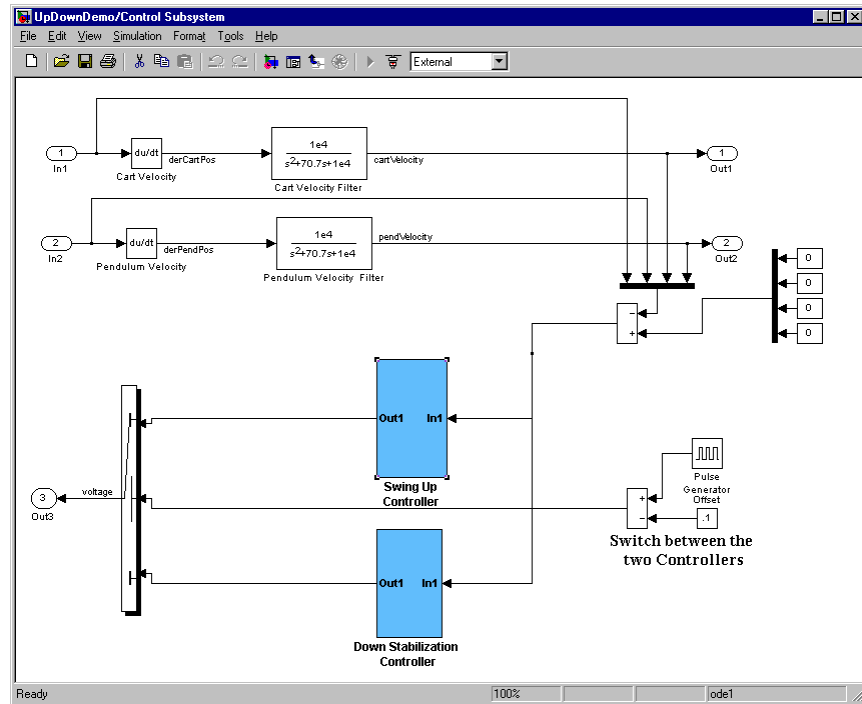
Figure 5-1: UpDownDemo

Double click the blue Control subsystem block to reveal its structure with the two controllers for each timed interval.



DIGITAL PENDULUM CONTROL EXPERIMENTS

Experiment 3 UpDownDemo





6 Customised Control

RTWT combines the powerful functionality of MATLAB, Simulink and Real-Time Workshop and allows users to implement any kind of control algorithm.

If you wish to implement a different kind of controller you may copy one of the supplied block diagrams, and simply replace the existing control blocks with customized control blocks (or subsystems).

However, before you start designing and implementing customized control algorithms, it is strongly recommended that you refer to the RTWT User's Manual and the Simulink User's Guide.



Notes



7 Some Common Problems

CranePID

- 1 If the Friction Compensation Parameter is set to high you may notice high frequency oscillations of the cart about its desired position. To remove these you should gradually reduce the friction compensation parameter value shown in Figure 3-12 until the oscillation stops.

Inverted PD

- 2 If the pendulum never reaches a vertically upright position, the parameter `umax`, the maximum power applied to the motor, may be too low (Figure 4-6). Try increasing this in small increments, until the pendulum swings with sufficient speed to reach this position.
- 3 If you wish to change other parameters (such as `alpha` or `beta`), then choose the parameter to vary and make small positive and negative increments to the initial value. Find the optimum value of *this* parameter which gives the "best" quality of control. Then, using this value and the same procedure find the optimum value of another parameter. After changing relevant parameters, you can repeat the sequence starting with the first parameter if necessary.



**DIGITAL PENDULUM
CONTROL EXPERIMENTS**

Chapter 7

Some Common Problems

Notes