# Implementation of Conventional and Neural Controllers Using Position and Velocity Feedback

Data Sheet

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**Overview:**
Our project objective is to design and evaluate different controllers for a small robot arm-motor platform from Quanser Consulting. Our main effort will be to work in a software environment on a 200 MHz or higher Pentium Computer to develop the controllers and signal processing algorithms in C language. An internal A/D and D/A converter card is connected to the external plant as shown in Fig. 1. The plant consists of an amplifier, DC motor assembly, external gear train, external load, and potentiometer for the position sensor (also from Quanser Consulting). The feedback signal will be passed through an antialiasing filter, to the A/D converter, into the computer. The feedback voltage signal is proportional to the position of the robotic arm. The arm position, output position on Fig. 1, is the primary output of the system, although arm velocity will also be of interest.

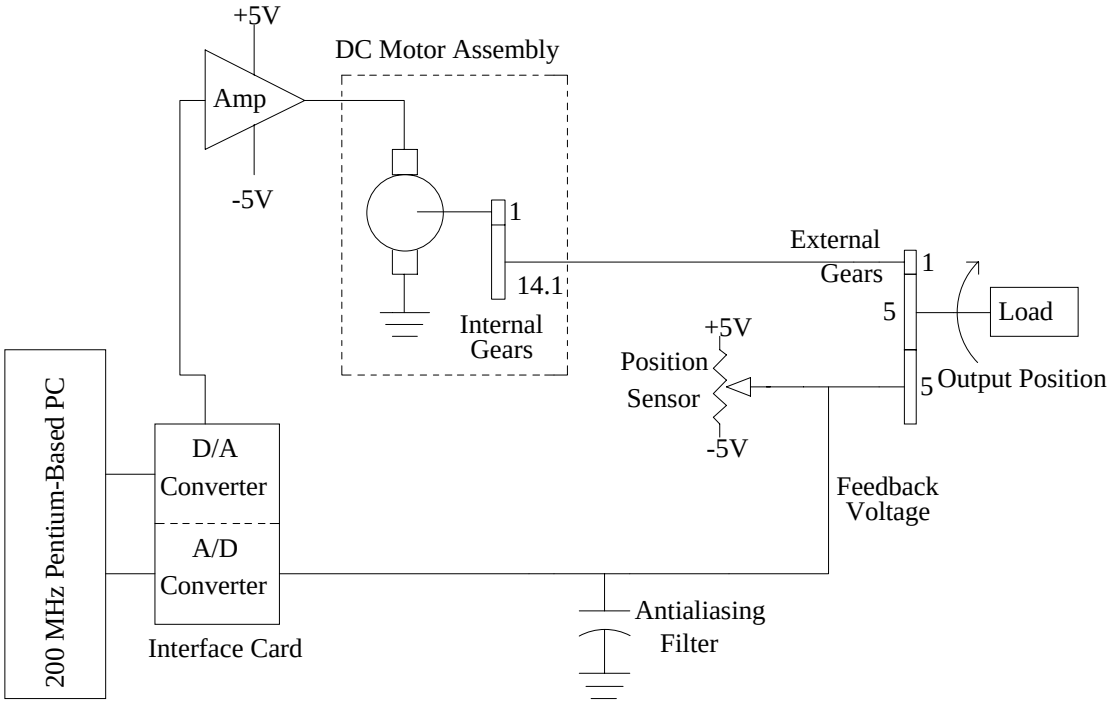



Fig. 1. Low Level System Block Diagram

**Hardware:**
The high-level system block diagram in Fig. 2 shows the main parts of the project. The robotic arm system is expanded in Fig. 1. It consists of mechanical devices and the circuitry to convert the input and output of the A/D and D/A converters to the proper analog signals. The D/A converter converts the PC signals to analog signals that will perform actions on the robot arm. The position sensor, where a velocity feedback loop will be added later, sends the position of the robot arm through an A/D converter back to

the PC. The Pentium-based PC will perform all the calculations, update display information, and generate the command signal. If the optional joystick is present in the system, the command signal will be generated by the user's interactions with the joystick. The programs will be written in C and used under windows. All the mechanical components are ready to use and Quanser Consulting supplied some PC programs.

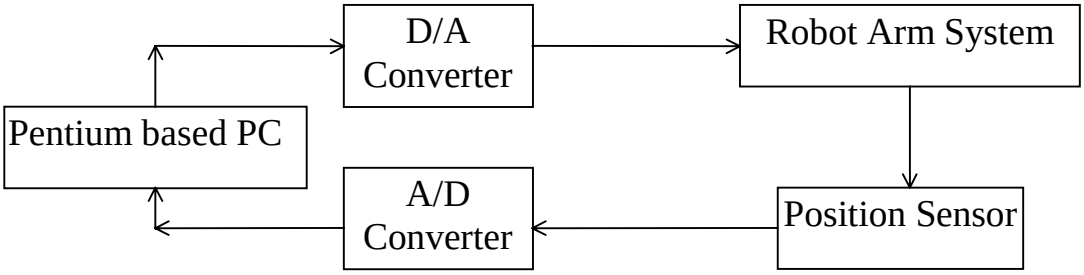



Fig. 2. High Level Block Diagram

**Modes of Operation:**
Two modes of operation will be incorporated into the product. The first mode is an option of connecting a joystick to one A/D channel and will allow the user to control (command) the robot arm position. An external digital input can be used to signal the software that a joystick is present. The other mode (default) will use an internal software command signal to control robot arm position. The user via keyboard will be able to change the set point (desired final position) and the slope of the command signal (velocity).

The signals that are important in this system are described below. They are separated into three categories (1) inputs, (2) outputs, and (3) internal signals to the computer that are important for controller evaluation and testing.

(1) Input signals to computer:
The letters in brackets refer to the letters in Fig. 3:

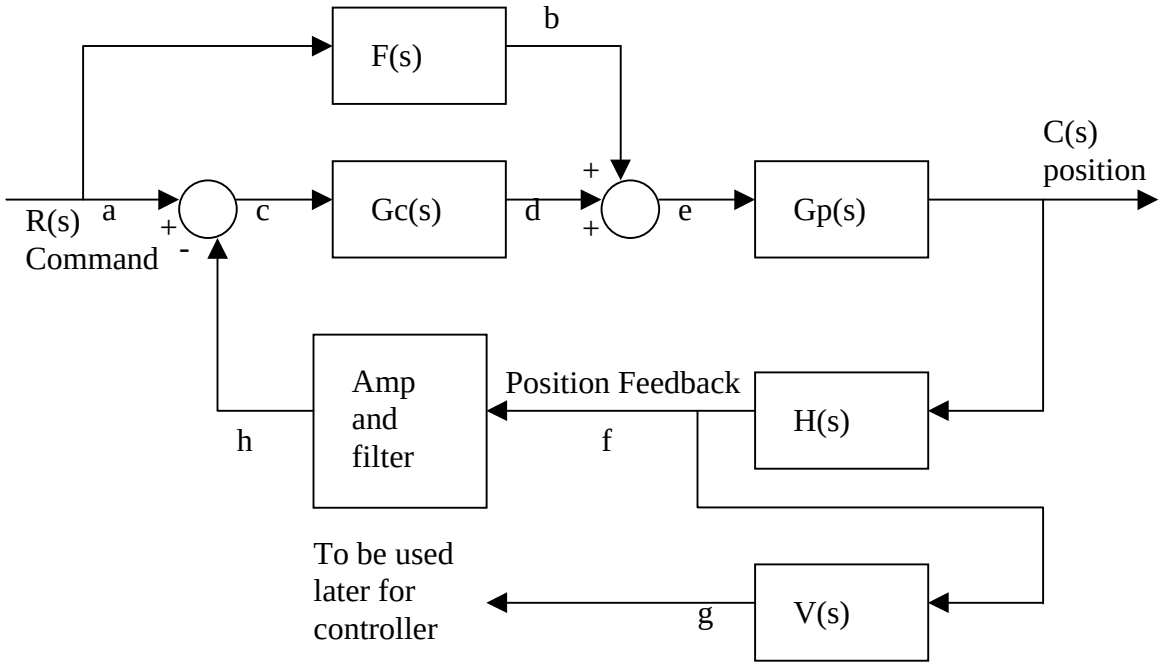
| **Signal** | **Description** |
|---|---|
| Voltage from position sensor (proportional to position)[f] | Used to help create the new control signal |
| Voltage from joystick | Used to create the command signal[a] |
| Digital input | Used to signal if joystick is present |

(2) Output signals from computer:
The letters in brackets refer to the letters in Fig. 3:

| **Signal** | **Description** |
|---|---|
| Control (Actuating) Signal[e] | Used to drive the robot arm |
| Calculated velocity from robot arm[g] | Used to help create the new control signal |

(3) Internal signals (in software, each will be displayed on computer monitor):
The letters in brackets refer to the letters in Fig. 3:

| **Signal** | **Description** |
|---|---|
| Command Signal[a] | Desired signal of robot arm position |
| Feed-Forward Signal[b] | The signal output from the feed-forward compensator |
| Error Signal[c] | The difference between the desired position and the calculated actual position |
| Conventional Controller Signal[d] | The signal output from the PID-type controller |
| Control (Actuating) Signal[e] | The signal created by the feed forward signal and the PID controller signal |
| Filtered and amplified position sensor output signal[h] | The filtered and amplified position signal |
| Calculated velocity signal[g] | The signal that is calculated by using the filtered position output signal |




F(s) is the feed-forward compensator implemented in software
Gc(s) is the PID-type controller implemented in software
Gp(s) is the plant this is part of the hardware
H(s) is the position sensor this is part of the hardware
Amp is an amplifier part of the hardware
V(s) is an algorithm to be determined for velocity feedback
C(s) robot arm position output
R(s) command generated in software

**Fig .3. Control Block Diagram**

**Software:**
In Fig. 4, the software flowchart is shown. In the table below the blocks are listed and described.

| **Blocks** | **Description** |
|---|---|
| Initialization | Interrupts will be setup to generate a 200Hz sampling (50ms). |
| Interrupt Service routine and Performing of PID controller | Send signals from the calculated values of the main program and interrupt service routine to the robot arm and to the monitor at user specified times. |
| Main Program | Will calculate values for the display, check the keyboard, read the joystick, and generate the command signal. |
| Keyboard | Gives the user a choice of which signals are to be displayed.<br>Type of controller can also be selected. |
| Display | Will show all internal and external signals chosen by the user. |
| Joystick Check | There is the possibility that the robot arm can be driven by a joystick or by PC commands. The connection will be checked and if yes the joystick position will be read and saved for the interrupt service routine. If not, the PC will generate the command signal. |
| Generate Command Signal | This option occurs when the joystick is not connected. The PC will calculate the command signal and save its value for the interrupt service routine. |

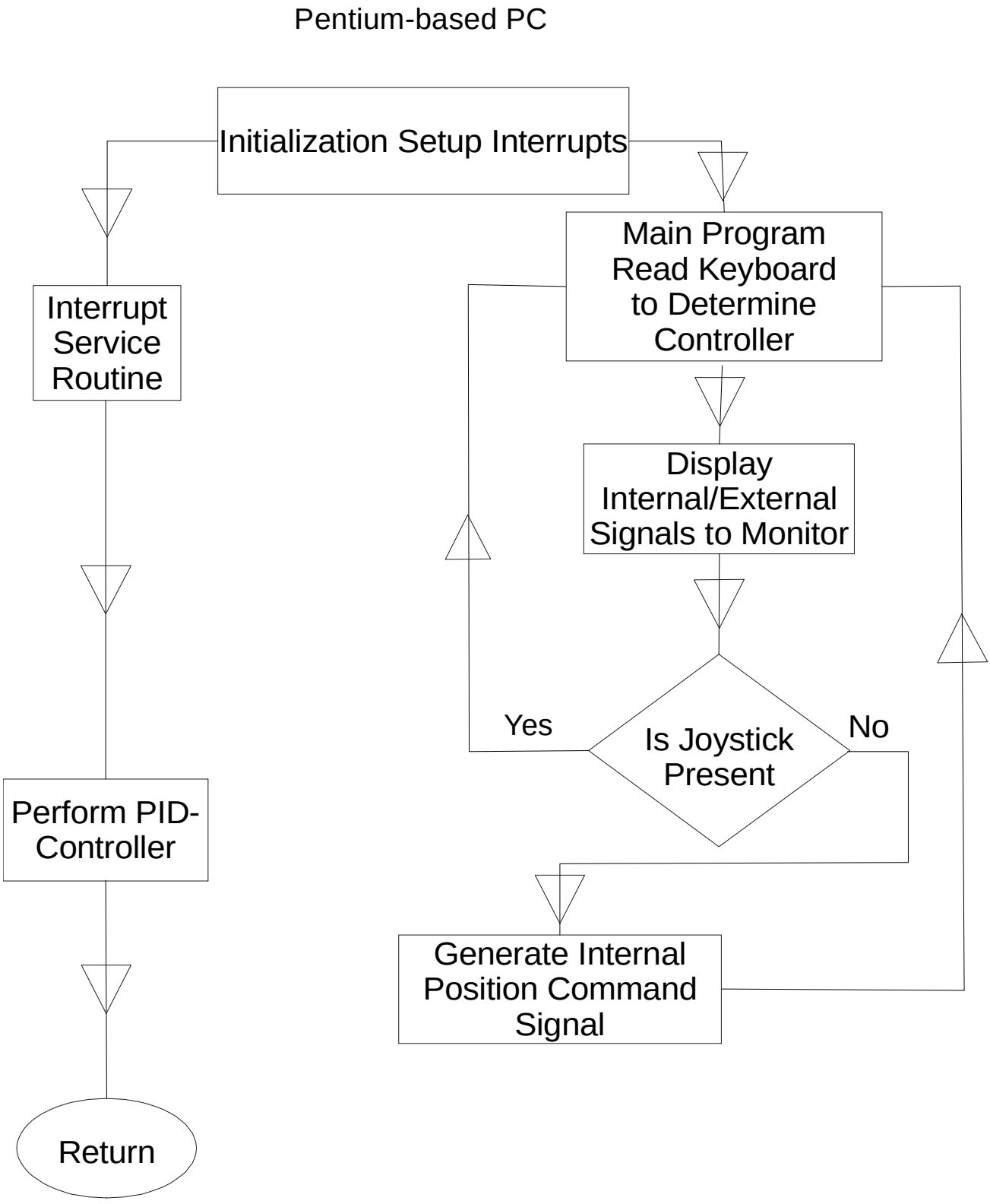



Fig. 4. Software Flowchart

**Patent Search:**
For our project it was more suitable to perform a literature search on the velocity algorithms that are suitable for our controller method. A tachometer will not be considered for this system because of cost and the low velocities associated with this small robot arm system. Instead we will calculate velocity from a position sensor. Two types of position sensors will be investigated. The analog position sensor consists of a potentiometer connected to a dual $\pm$ 5 volt supply. The potentiometer mechanical arm is connected to the external robot arm via a 1:1 gear. Therefore the potentiometer's arm voltage is proportional to position. For example, zero volts would correspond to a robot arm angle of zero degrees. The digital position sensor is a rotary encoder. The advantages of the digital sensor are improvement in reliability, the output frequency is proportional to velocity, and the output is independent of power supply changes. The disadvantage is a loss in position resolution. Both sensors will be used in our controller designs and compared with the different velocity calculation algorithms.

The first velocity calculation algorithm that will be implemented will be based on Tustin's method [1]. Essentially we will design an analog differentiator (phase lead network) and convert it to a digital filter using Tustin's method. Tustin's method is also called the bilinear transformation method. The second method will use a polynomial curve fit algorithm to approximate velocity from current and past position readings. This algorithm is currently being researched by our advisor, Dr. Dempsey. There are numerous velocity calculation algorithms that would require extensive design and implementation time. One method uses a neural network approach to improve the output velocity information by reducing the level of noise [2]. This neural method would require more time than is allowed for our total senior project. The two approaches that we will design and implement will be tried with both types of position sensors and should provide valuable information to Dr. Dempsey for his 2000 senior project group.

**Standards:**
The Controller software will be implemented in C-code and installed on an IBM compatible computer. The standards for the project are shown in the table below.

| **Device** | **Requirement** |
|---|---|
| Computer | 486 or higher processor<br>IBM compatible<br>Math co-processor |
| DOS | Version 6.2 |
| Windows | Version 3.11 or higher |
| 1 Bus Expansion | For A/D and D/A converter card |

**Specifications:**

Inputs

1. Step Function: The step function to run the robot arm system is shown in Fig. 5.

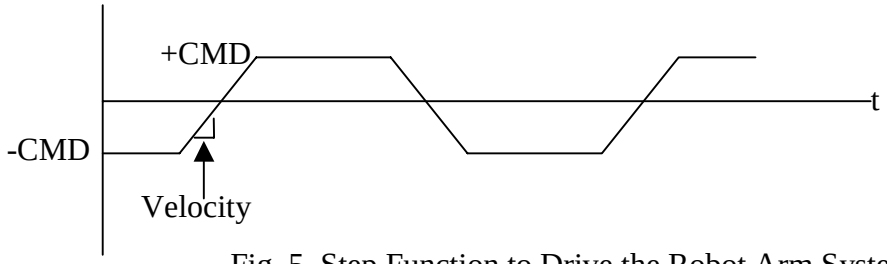



Fig. 5. Step Function to Drive the Robot Arm System

   A. $|CMD| \leq 90°$
   B. $Velocity_{max} = 45°/sec$

Outputs

1. Position
   A. Percent Overshoot(%O.S.) = 5%
   B. Time to First Peak(tp) = 3s
   C. Magnitude of Peak in Frequency Domain(Mp) = 1.32dB
   D. Frequency of Peak($\omega p$) = 170mHz
   E. Bandwidth Closed Loop($BW_{cl}$) = 290mHz
   F. Phase Margin(PM) = 50°
   G. Gain Margin(GM) = 6dB
   H. Steady State Error(ess) < 2°

2. Velocity
   A. Tracking Error < 2°

**User Interface:**

The user interface for the robot arm system is a computer monitor and a keyboard. The preliminary monitor display is shown in Fig. 6. The keyboard will allow the user to change the different options of the robot arm system. Also, a help screen will be added to add in the keystrokes to change the options.

User controlled setting are shown in the table below.

| **Options** | **Description** |
|---|---|
| Motor On/Off | Turns motor on or off |
| Kp gain | Set the gain of the system |
| Command Set Point | The final robot arm angle |
| Ramp Velocity | Has to be less than 45°/sec |
| Step Frequency | The frequency of the step function |
| Plotting Variable | The variable that is shown on the plot |
| Controller Type | Type of controller to be used |

Interface display shows the following:

| **Display** | **Description** |
|---|---|
| Real Time | Time the program has been running |
| Cycles | How many times the systems has been ran |
| Actual Position | The position of the arm |

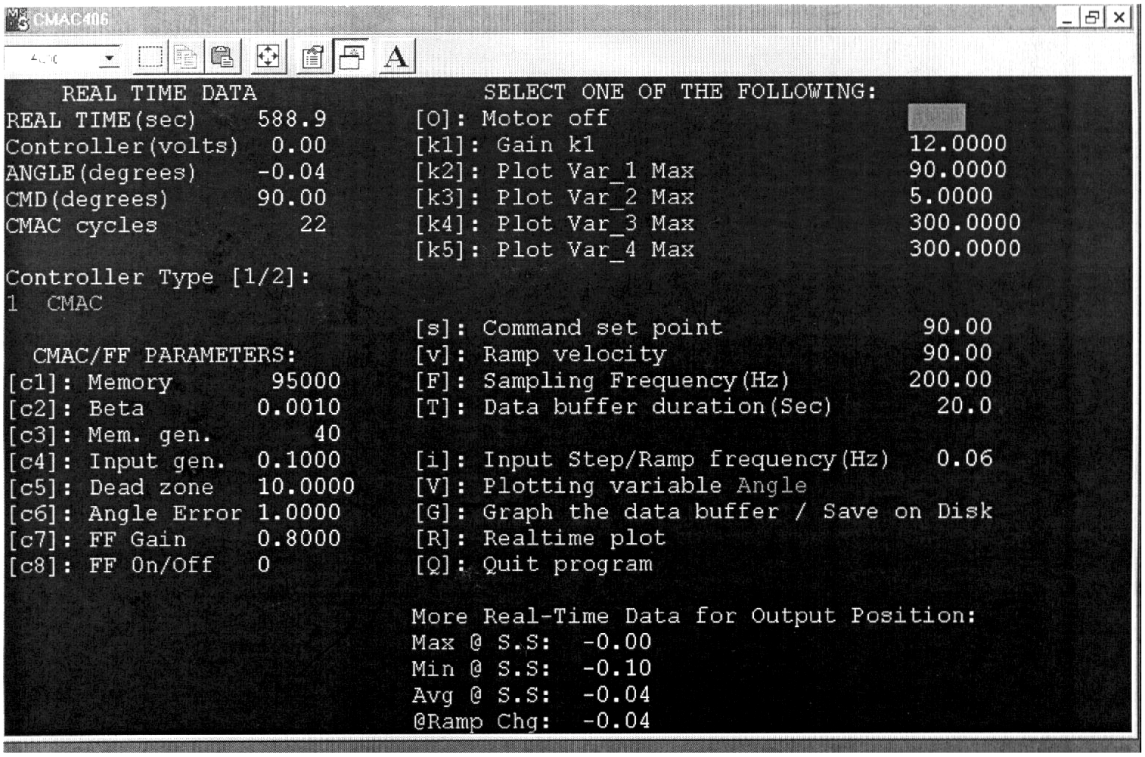



Fig. 6. User Interface

**Final Testing:**

To test the final system a command signal will be entered. With this command signal the different types of controllers will be used and the final position signal of the robot arm will be shown. With the more advanced type of controllers the final angle will be closer to the desired angle. Then the neural network will be shown using velocity feedback. With this controller the system will learn to go the desired angle. Also, to help show the system works the real-time graphs will be used. To prove that the system is working correctly we will compare the experimental position curve versus time with a curve generated from a simulation environment(MATLAB).

**References:**

[1] Charles L. Phillips and Royce D. Harbor. Feedback Control Systems, 4th edition, Prentice-Hall Inc., 1999.

[2] Olli Vainio. "Adaptive Derivative Estimation for Delay-Constrained Acceleration Measurement", *IEEE Transactions on Industrial Electronics*, Vol. 46, No. 5, October 1999.