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Current feedback for shock disturbance attenuation in a compact disc player

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Abstract

Control of compact disc mechanisms is highly challenging not least due to the many conflicting control objectives arising from a large number of disturbances of rather different physical natures. A method is proposed which enables the control system to distinguish between some of the disturbance classes. A significant robustness problem is solved by a simple adaptive scheme which takes real-time constraints into consideration. The results show a significant attenuation of mechanical shocks for the compact disc mechanism.

1 Introduction

The control problem associated with tracking and focusing the laser beam of a light pen in compact disc (CD) drives is highly nontrivial even for conventional CD players. Needless to say, the new standards (such as DVD, CD-writable, etc.) which have much tighter specifications offer even more challenges from a control point of view.

The basic problem for the control system is the huge variety of sources for disturbances and model errors which pose rather conflicting constraints on the control system in terms of bandwidth etc. As an example, a bright scratch in the surface of the CD requires the bandwidth to be low, since otherwise the light pen would follow the scratch rather than the track. On the other hand, in car or discotheque applications, the bandwidth has to be rather high in order for the CD player to be robust to shocks caused by bumpy roads resp. massive dancing or loud speaker feedback.

Both robust and adaptive control approaches have been applied to the CD control problem, see e.g. [DSB92, SSB96] and references therein. Both approaches suffer from drawbacks; the robust control method can offer only a rather limited bandwidth, since part of the performance is really sensitive to parameter variation - this will be elaborated further below. The adaptive approaches are difficult to implement in real time software, since the sampling frequency of the system is rather high for other reasons, hence even with very fast dedicated processors, the computations can not be completed between subsequent samples. Finally, both methods also have difficulties with the trade-off between the apparently conflicting design specifications mentioned above.

In order to be able to distinguish between the various disturbances, in [YNK94] it was suggested to equip the system with an additional measurement. The measurement suggested was the current in the actuators which would reveal a mechanical shock if deviating from its intended value.

In [YNK94] good results were obtained with suppression of mechanical disturbances at low frequencies. However, due to robustness problems, the method can not be immediately applied to disturbances at higher frequencies. This is unfortunate, since a number of commercial disk drives have resonance frequencies in their mechanical constructions at relatively high frequencies.

In this paper, a method will be proposed which utilizes an additional current measurement as suggested in [YNK94]. A very simple, yet effective adaptive scheme is suggested which allows disturbances at relatively high frequencies to be attenuated.

For simplicity, we shall discuss only the feedback loop from the additional measurement. However, one of the virtues of the proposed approach is that there is a decoupling between the two loops. This means that the conventional CD controller can be used immediately in combination with the proposed inner loop controller.

2 Current feedback for a light pen

A CD player mechanism has a number of control loops, most of which are rather slow and of less significance. Two of these, however, are virtual bottlenecks in the CD operation. One of these two control loops are involved with focusing of the laser beam from the light pen onto the optical disc, and the other is involved with tracking the information on the disc. The actuators involved with these two loops are

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typical integrated in one unit. They roughly work like DC motors and typically they share the same permanent magnet, although they operate in orthogonal directions. For a closer description, see [DSB92, SSB96, YNK94].

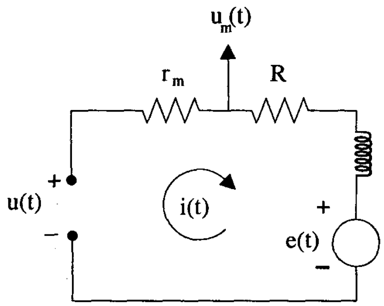

Figure 1: Electromechanical diagram of radial or focus actuator.

Figure 1 shows the electromechanical diagram of the radial or focus actuator where $u(t)$ is the control signal and R, L together with the induced voltage, $e(t)$, represent the coil of the actuator. A resistance r_m in inserted in parallel in order to calculate the current through the coil by measuring the voltage across r_m.

The basic equations for the radial or focus actuators are:

$$u(t) = (R + r_m)i(t) + L\dot{i}(t) + Bl\dot{x}(t) \tag{1}$$

$$m\ddot{x}(t) = Bli(t) - c\dot{x}(t) - kx(t) + F_y(t) \tag{2}$$

The radial and focus actuators are inductive. The dynamics related with the inductive part L, however, lies far outside the desired bandwidth of the control system, so the inductive effects will be disregarded in this paper. This leads to the following block diagram shown in figure 2.

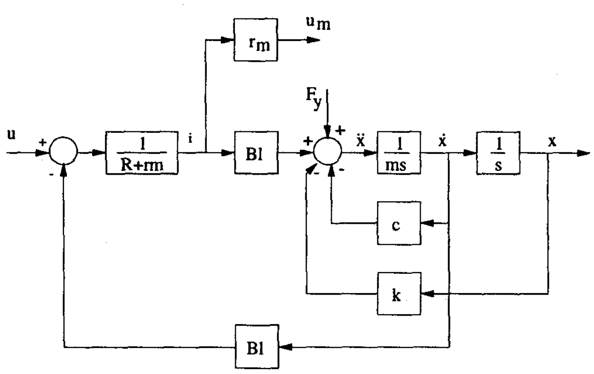

Figure 2: *Block diagram for light pen equipped with current sensor.*

The block diagram has 2 inputs, the controller voltage $u(t)$ and an external disturbance force $F_y(t)$, and 2 outputs, the lens position $x(t)$ and the voltage across a measurement resistance $u_m(t)$. Hence, it can be drawn as shown in figure3.

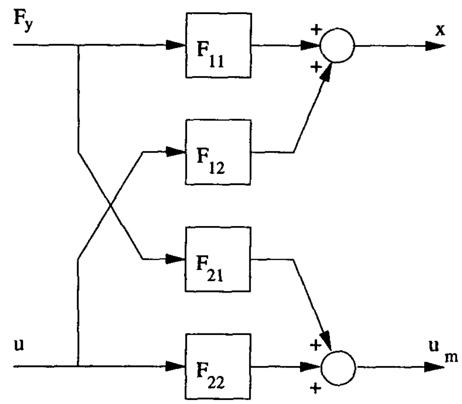

Figure 3: *Block diagram for light pen actuator with resistor measurement.*

where

$$F_{11}(s) = \frac{x(s)}{F_y(s)} = \frac{\frac{1}{m}}{s^2 + (\frac{c}{m} + \frac{(Bl)^2}{m(R+r_m)})s + \frac{k}{m}} \tag{3}$$

$$F_{12}(s) = \frac{x(s)}{u(s)} = \frac{\frac{Bl}{m(R+r_m)}}{s^2 + (\frac{c}{m} + \frac{(Bl)^2}{m(R+r_m)})s + \frac{k}{m}} \tag{4}$$

$$F_{21}(s) = \frac{u_m(s)}{F_y(s)} = \frac{-\frac{r_m Bl}{m(R+r_m)}s}{s^2 + (\frac{c}{m} + \frac{(Bl)^2}{m(R+r_m)})s + \frac{k}{m}} \tag{5}$$

$$F_{22}(s) = \frac{u_m(s)}{u(s)} = \frac{\frac{r_m}{R+r_m}(s^2 + \frac{c}{m}s + \frac{k}{m})}{s^2 + (\frac{c}{m} + \frac{(Bl)^2}{m(R+r_m)})s + \frac{k}{m}} \tag{6}$$

In the sequel we shall investigate the effect on the transfer function $F_{11}(s)$, see (3), when a negative impedance is introduced in series with the coil, corresponding to a reduction of $R + r_m$. It is immediate that the cut-off frequency

$$\omega_0 = \sqrt{\frac{k}{m}} \tag{7}$$

is independent of the resistance. The damping can be found as

$$\zeta = \frac{c + \frac{(Bl)^2}{R+r_m}}{2\sqrt{km}} \tag{8}$$

By inserting the values:

$$R = 18\,\Omega \quad r_m = 1.0\,\Omega \quad m = 0.56\,g \quad k = 19.9\,N/m$$
$$Bl = 0.282\,N/A \quad c = 0.0465\,N{\cdot}s/m \tag{9}$$

figure 4 is obtained which shows how an external force disturbance influences the position x. Note, that the combined resistance has to be very small in order to introduce any significant damping in the area of interest which starts from 80 Hz (approx. 500 rad/s) and up to the desired bandwidth which ranges from 500-1000 Hz, depending on the application of the CD drive.

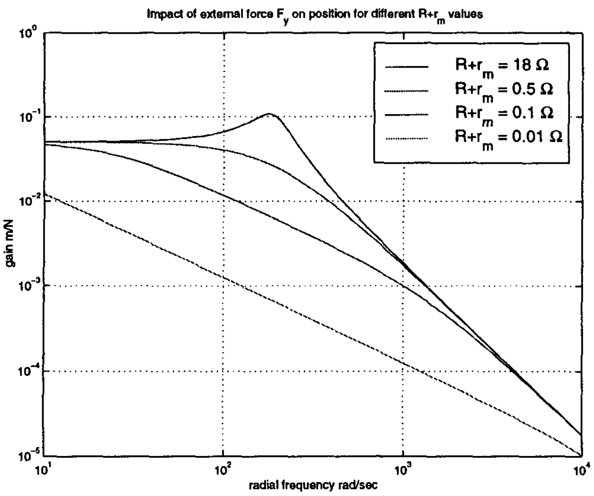

Figure 4: *The effect of varying coil resistance. Bode plot for transfer function from the external force to the position.*

Since a fixed negative impedance never will compensate exactly the intrinsic impedance, this poses the question of stability if the resulting impedance becomes negative. From (3) is seen that the coefficient for s in the denominator will become negative whenever

$$\frac{c}{m}+\frac{(Bl)^2}{m(R+r_m-R_c)}>0$$
$$\Updownarrow$$
$$(R+r_m-R_c>0)\vee(R+r_m-R_c<-\frac{(Bl)^2}{c}) \qquad (10)$$

where $-R_c$ is the negative impedance we wish to implement.

With the actual values, instability arises in the interval

$$-1.71<R+r_m-R_c<0 \qquad (11)$$

Hence, optimality is obtained extremely close to the stability boundary. This if course causes huge robustness problems.

3 A compensator for attenuation of external force disturbances

In figure 5 a compensator block has been added to the diagram for the actuator. The intention of this block is to eliminate or reduce the signal path from F_y to x. To simplify this, a feedforward block $-F_{22}$, has been introduced which eliminates the signal path from the K block to u_m. Now, in order to eliminate the signal path from F_y to x what remains is to fulfill the following relation:

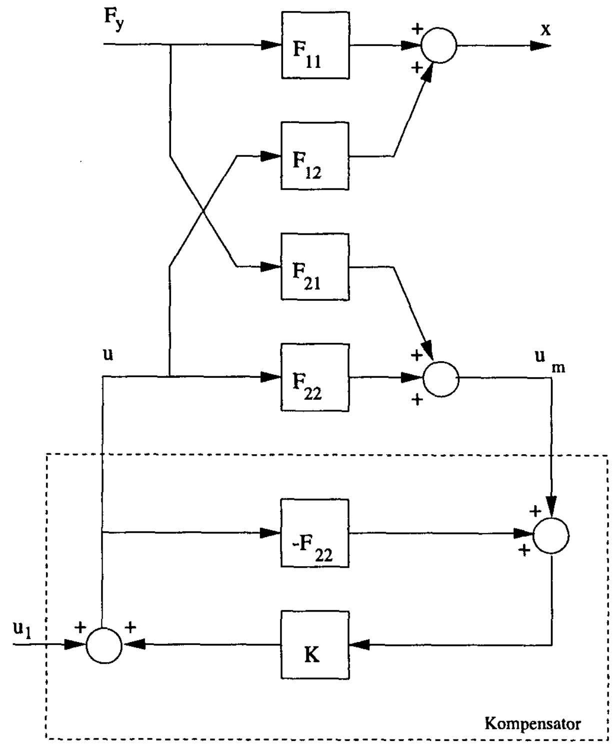

Figure 5: *Light pen actuator with compensator.*

$$F_{11}=-F_{21}KF_{12}\Rightarrow K=-\frac{F_{11}}{F_{12}F_{21}} \qquad (12)$$

Inserting the transfer functions derived above, we obtain:

$$K(s)=\frac{m(R+r_m)^2}{r_m(Bl)^2}\cdot\frac{s^2+(\frac{c}{m}+\frac{(Bl)^2}{m(R+r_m)})s+\frac{k}{m}}{s} \qquad (13)$$

With this value for $K(s)$, the transfer function for the combined compensator becomes:

$$u(s)=C_1(s)u_m(s)+C_2(s)u_1(s) \qquad (14)$$

where

$$C_1(s)=\frac{R+r_m}{r_m} \qquad (15)$$

and

$$C_2(s)=\frac{(Bl)^2}{m(R+r_m)}\cdot\frac{s}{s^2+(\frac{c}{m}+\frac{(Bl)^2}{m(R+r_m)})s+\frac{k}{m}} \qquad (16)$$

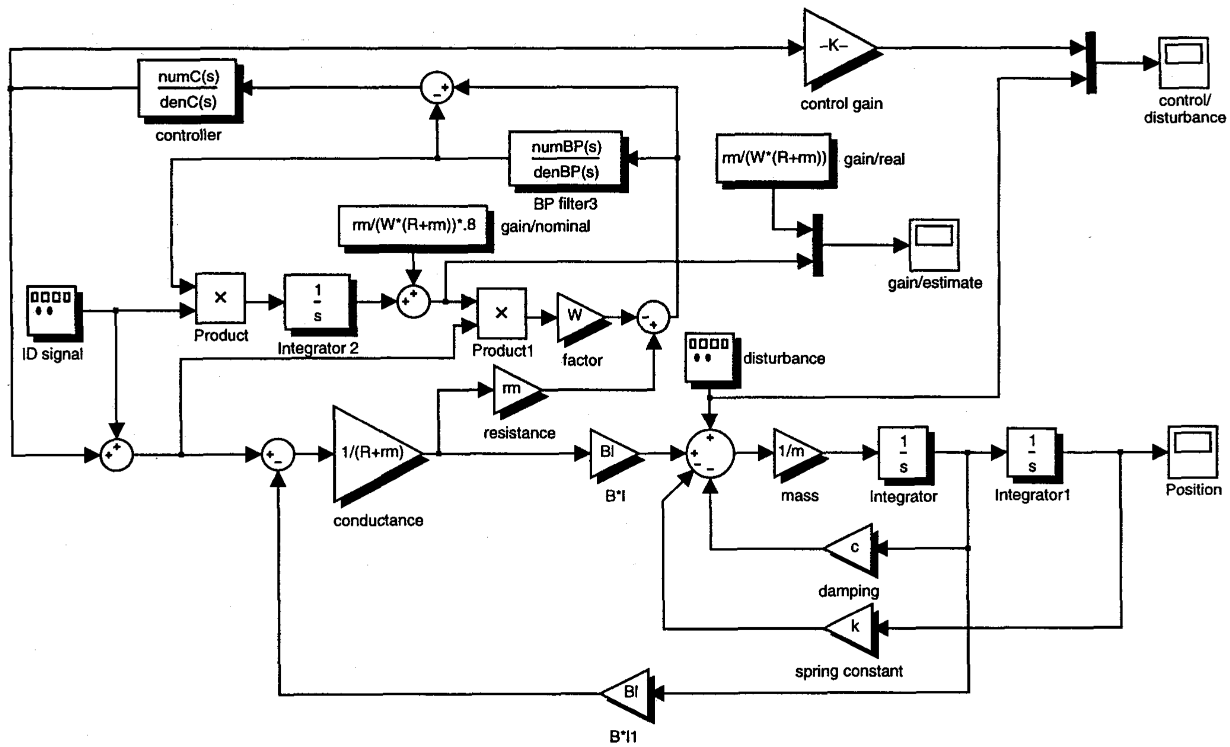

Figure 6: Adaptive scheme based on estimation of intrinsic impedance

$C_1(s)$ provides a positive feedback from the current as measured over the resistance r_m to a voltage in series with the coil which is in fact equivalent to negative impedance. Using the value in (15), the intrinsic impedance is exactly annihilated and resulting impedance becomes zero. This is of course unrealistic in practice, due to the stability problems mentioned above. In the sequel we shall present an adaptive architecture which overcomes this problem.

4 An adaptive structure for achieving robustness and performance

As we have seen above, it is in principle possible to achieve considerable disturbance attenuation by using a feedback from the current measurement, provided the actuator resistance is well known. On the other hand, there is a significant robustness problem involved with this resistance which might vary a lot due to production variation or it might vary with temperature when the CD mechanism is in operation.

This suggests that it might be worthwhile to try an online identification of the above mentioned resistance. The scheme suggested is shown in figure 6.

The basic idea in the setup of figure 6 is to employ an online identification signal with a high frequency. This high frequency (3000 Hz in the experiments) lies far outside the actuator bandwidth so it does not move the optical system. Hence, when the ID signal is applied to the input, the component of the ID frequency in the measured current is simply the open loop DC gain of the input path.

This is utilized in a nonlinear feedback which inputs to an integrator (Integrator 2 in figure 6). This feedback loop is engineered in such a way that the only stable equilibrium is when an estimated gain equals the real open loop DC gain from input to current measurement.

The estimated gain is used to annihilate the intrinsic gain, such that the modified output is a direct measurement of the velocity $\dot{x}$ of the lens system.

The architecture also implies that the open loop gain from control input to modified current measurement vanishes. Hence, the control signal directly adds to any mechanical disturbance.

All that is left now, is to estimate the disturbance from the velocity measurement, change its sign and feed it forward from the control input. Since only relatively high frequencies (300-800 Hz) were of interest to our application, the controller had a band pass filter, such that compensation only was done in this frequency range.

In figure 7, the resulting closed loop identification results is shown.

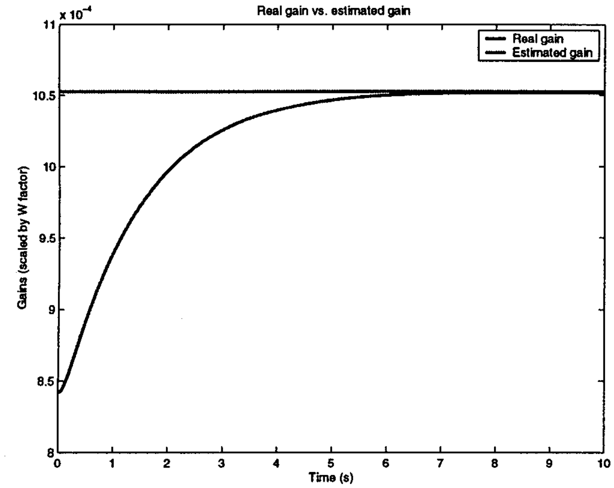

Figure 7: Real and estimated gains in adaptive scheme

The estimated gain reaches the real gain in approximately 7 seconds from an initial nominal gain which is 20% in error. In the experiment, an external harmonic force disturbance with a frequency of 300 Hz was introduced.

In figure 8 it is seen how the control signal improves as the gain estimation becomes more and more accurate.

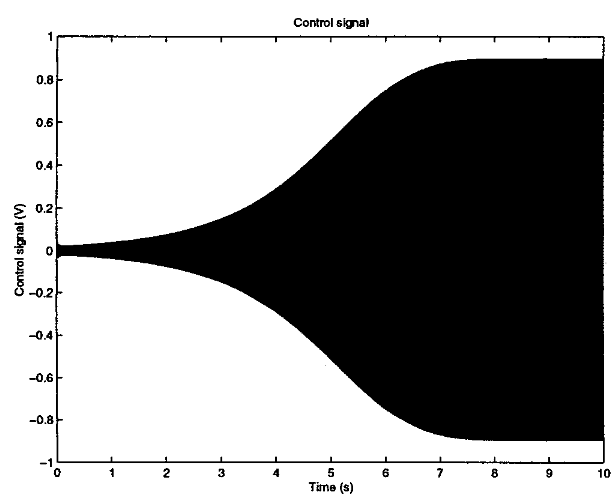

Figure 8: Control signal in adative scheme

The robustness problems mentioned above is easily recognized. Only when the gain has been estimated within approximately 1%, the control signal becomes of any significance. Although difficult to see from the figure, the control signal is a harmonic oscillation (except from the varying amplitude) at the same frequency as the disturbance.

Finally, the disturbance decoupling is shown in figure 9. The position in similarity with the control signal is dominated by a 300 Hz component. It is seen how the control system is able to attenuate this component significantly as the estimated gain of the ID loop approaches the real gain.

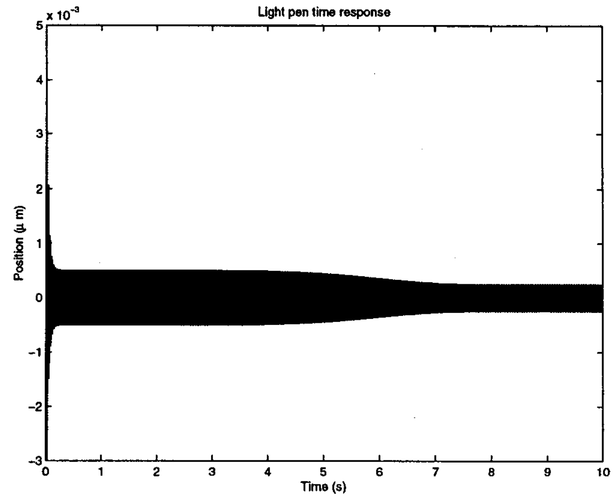

Figure 9: Position time response to harmonic force excitation

5 Conclusions

Using an additional current measurement, it is possible to distinguish between external mechanical disturbances and other disturbances in the control of a compact disc mechanism.

Theoretically, it is straightforward to implement a feedback from this additional measurement to attenuate such external mechanical disturbances.

However, performance is achieved only very close to the stability boundary, and the system becomes highly sensitive to tiny variations of the actuator resistances, such as will occur due to temperature variations.

The proposed method, though, overcomes the robustness problem by introducing a nonlinear (adaptive) loop which estimates the sensitive parameter online. Based on this estimation, the controller reduces even high frequent mechanical disturbances effectively.

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