Internal Model Control

Seminar Project Report

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Brief Introduction:

The internal Model Control philosophy relies on the Internal Model Principle, which states that control can be achieved only if the control system encapsulates, either implicitly or explicitly, some representation of the process to be controlled. In particular, if the control scheme has been developed based on an exact model of the process, then perfect control is theoretically possible.

It means that if we have complete knowledge about the process (as encapsulated in the process model) being controlled, we can achieve perfect control. It also tells us that feedback control is necessary only when knowledge about the process is inaccurate or incomplete.

Why I took it up:

Internal Model Control is an interesting approach to control system which differs from the traditional feedback control we have studied so far.

I thought it would interesting to study the advantages (or disadvantages) of Internal Model Control compared to that of feedback control._

OVERVIEW

As stated earlier, the IMC (Internal Model Control) philosophy is based on the Internal Model Principle.

The Internal Model Principle

control can be achieved only if the control system encapsulates, either implicitly or explicitly, some representation of the process to be controlled.

Perfect control is theoretically possible if the control scheme has been developed based on an exact model of the process.

Consider, for example, the system shown in the diagram below:

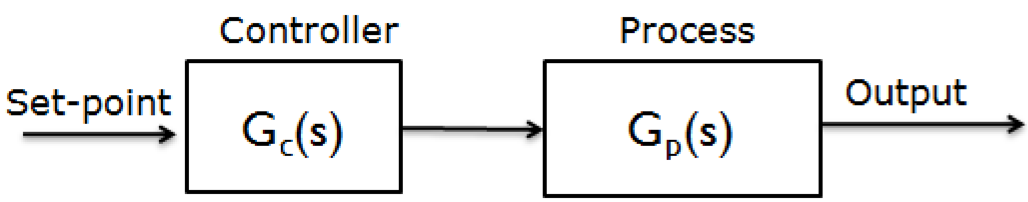

Figure 1

A controller, $G_c(s)$, is used to control the process $G_p(s)$. Suppose, is a model of $G_p(s)$. By setting $G_c(s)$ to be the inverse of the model of the process, And if $G_p(s)=$ (i.e. the model is an exact representation of the process), then it is clear that the output will always be equal to the setpoint. Notice that this ideal control performance is achieved without feedback. What this tells us that if we have complete knowledge about the process(as encapsulated in the process model) being controlled, we can achieve perfect control. It also tells us that feedback control is necessary only when knowledge about the process is inaccurate or incomplete.

The IMC Strategy

In practice, however, process-model mismatch is common. The process model may not be invertible and the system is often affected by unknown disturbances. Thus the above open loop control arrangement (Figure 1) will not be able to maintain output at setpoint. Nevertheless, it forms the basis for the development of a control strategy that has the potential to achieve perfect control. This strategy, known as Internal Model Control (IMC), has the general structure depicted in Figure 2.

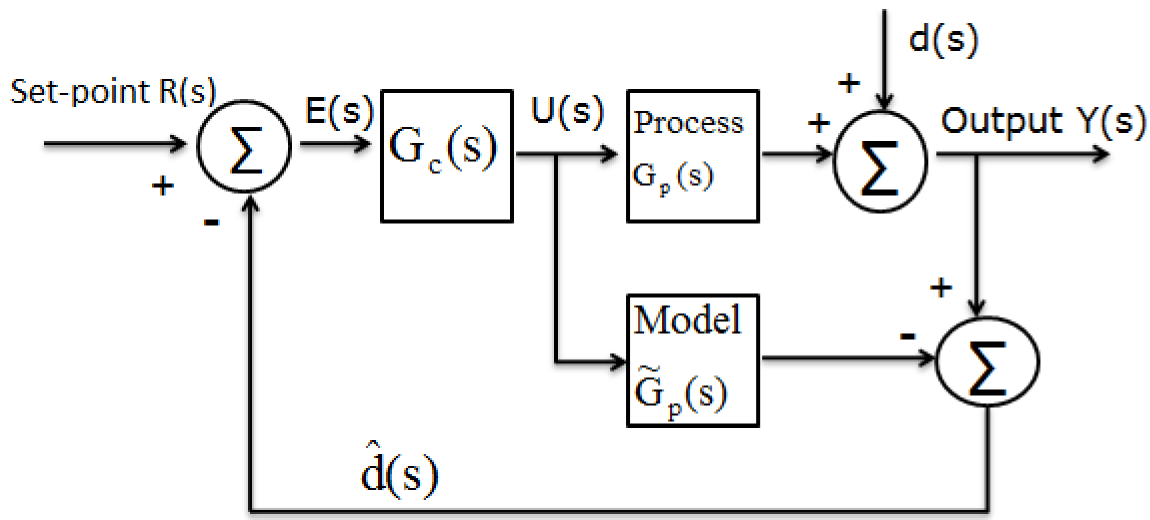

Figure 2

In the diagram, d(s) is an unknown disturbance affecting the system. The manipulated input U(s) is introduced to both the process and its model. The process output, Y(s), is compared with the output of the model, resulting in a signal (s). That is,

If d(s) is zero for example, then is a measure of the difference in behavior between the process and its model. If , then is equal to the unknown disturbance. Thus may be regarded as the information that is missing in the model, , and can therefore be used to improve control. This is done by subtracting from the setpoint R(s), which is very similar to affecting a setpoint trim. The resulting control system is given by, Thus,

Since

The closed loop transfer function for the IMC scheme is therefore

or

From this closed loop expression, we can see that if and if then perfect setpoint tracking and disturbance rejection is achieved. Notice that, theoretically, even if , perfect disturbance rejection can still be realized provided .

Additionally, to improve robustness, the effects of process-model mismatch should be minimized. Since discrepancies between process and model behavior usually occur at the high frequency end of the system's frequency response, a low-pass filter is usually added to attenuate the effects of process-model mismatch. Thus, the internal model controller is usually designed as the inverse of the process model in series with a low-pass filter. The order of the filter is usually chosen such that controller transfer function is proper.

SIMULATIONS

Simulations were done by creating a Simulink model of the IMC scheme (as shown in Figure 2) using the following transfer functions.

Transfer Functions used:

$$\text{Process}: G_p(s) = \frac{1}{(1+s)} \cdot \frac{(1-0.05s)}{(1+0.05s)}$$

$$\text{Model}: \widetilde{G}_p(s) = \frac{1}{(1+s)}$$

$$\text{Controller}: G_c(s) = (1+s) \cdot \frac{1}{(1+0.1s)^2}$$

The process transfer function has a delay component (in Padé approximation form) which is not included in the model transfer function. This was done to simulate process-model mismatch.

The controller transfer function is the inverse of model transfer function, with an additional term to make the transfer function proper.

The unit step response of the IMC scheme was recorded and compared with that of the proportional gain control (of the same process) method.

Figure 3 & 4 show the unit step response of the proportional gain control & IMC method respectively (without noise).

Figure 5 & 6 show the unit step response of the proportional gain control & IMC method respectively (with noise).

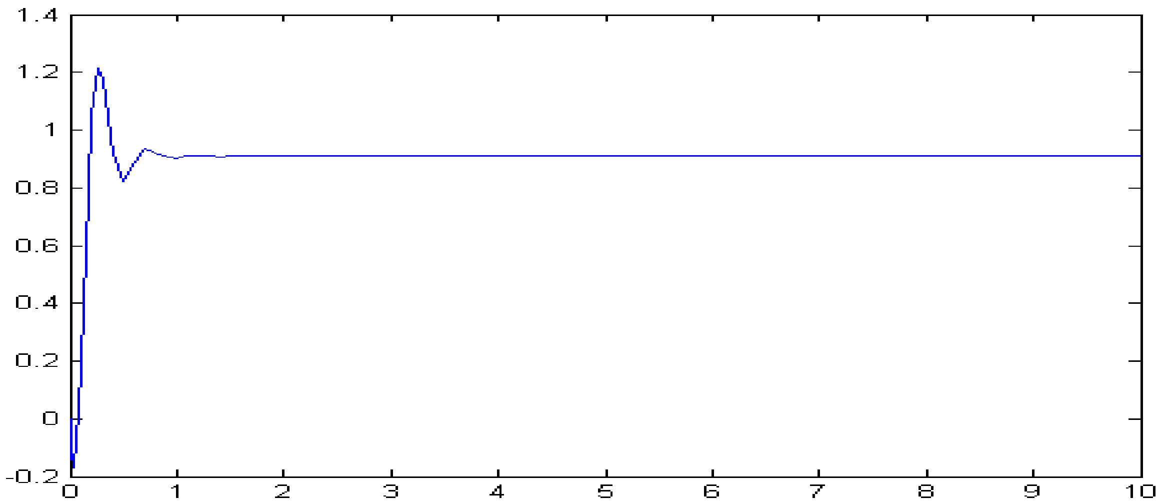

Figure 3

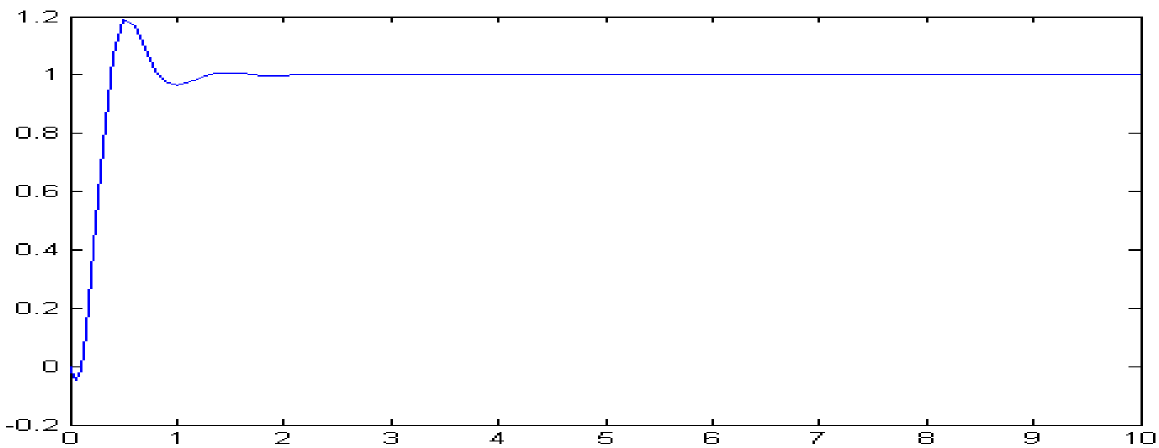

Figure 4

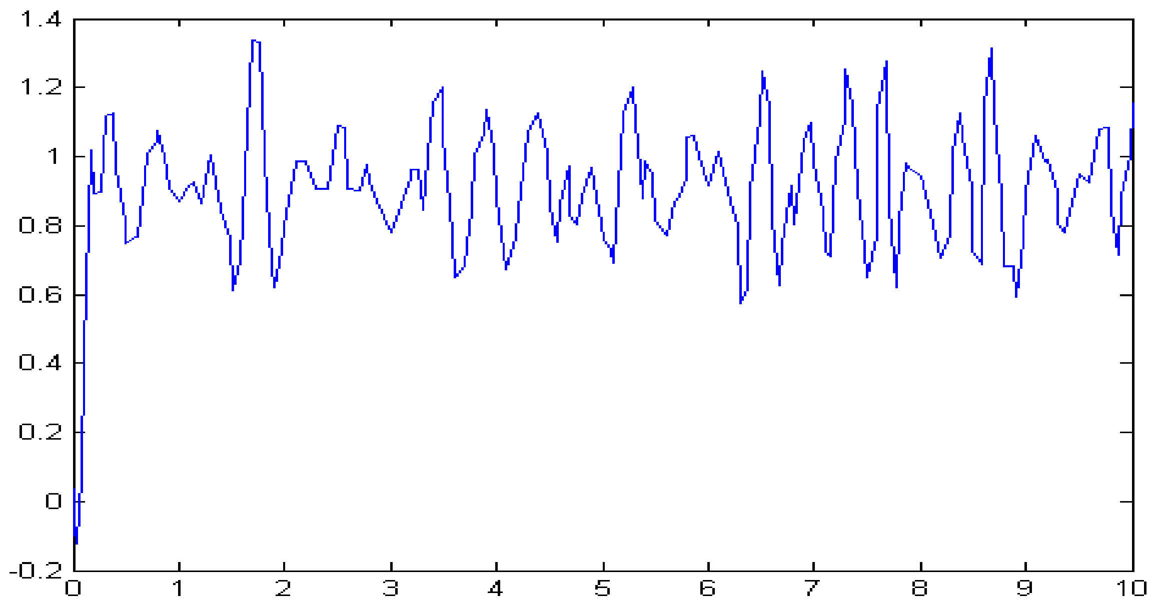

Figure 5

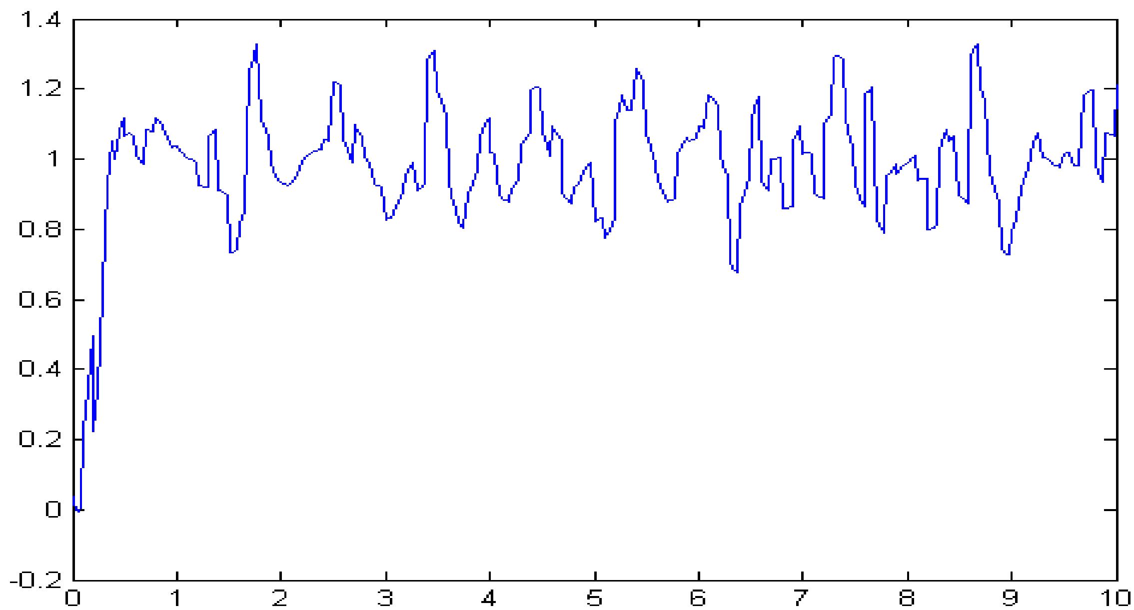

Figure 6

It can be seen that IMC method yielded no steady state error, has lower negative excursion and has somewhat better noise immunity.

In the above simulation, the transfer function used for the controller:

$$\text{Controller}: G_c(s) = (1+s) \cdot \frac{1}{(1+0.1s)^2}$$

General form:

$$\text{Controller}: G_c(s) = (1+s) \cdot \frac{1}{(1+\alpha \cdot s)^2}$$

$$(\alpha = 0.1 \text{ used in previous simulation})$$

Another Simulink simulation was done to study the effect of varying value. The transfer functions used were

Transfer Functions used:

$$\text{Process}: G_p(s) = \frac{1}{(1+s)} \cdot \frac{(1-0.05s)}{(1+0.05s)}$$

$$\text{Model}: \widetilde{G}_p(s) = \frac{1}{(1+s)}$$

$$\text{Controller}: G_c(s) = (1+s) \cdot \frac{1}{(1+\alpha \cdot s)^2}$$

Figure 7 & 8 show the simulation result (without noise & with noise respectively).

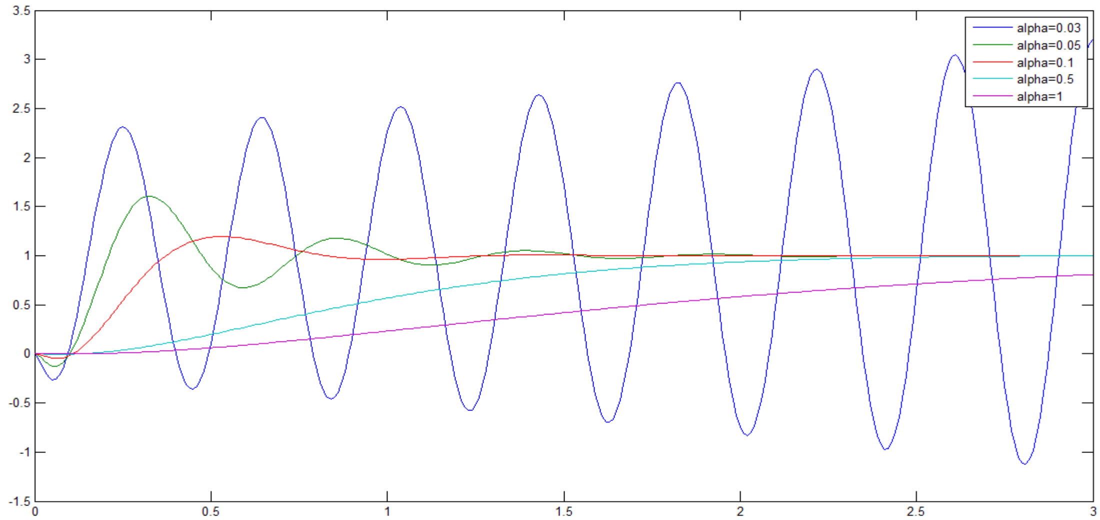

Figure 7

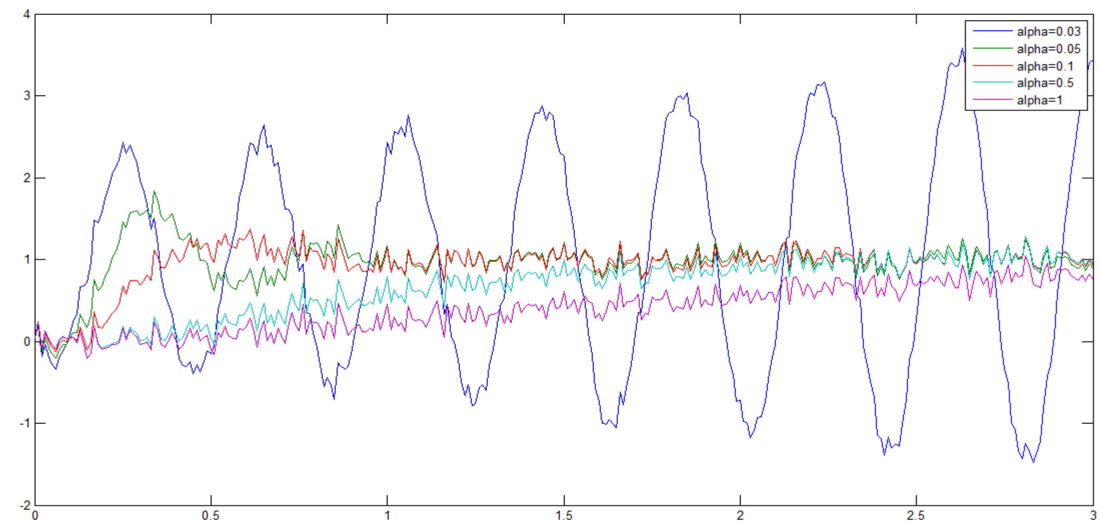

Figure 8

It can be observed that lowering the value makes the system response more & more oscillatory (the system may even become unstable beyond a point). On the other hand, increasing value makes the system sluggish.

So choosing the best value is a trade-off.

It should be noted that increasing value makes the corresponding pole more dominant.

Yet another Simulink simulation was done to investigate the capability of IMC method in handling process-model mismatch. For this, a 4th order process transfer function was used while the model transfer function was a 2nd order approximation of it.

Transfer Functions used:

$$\text{Process}: G_p(s) = \frac{(1 - 0.05s)}{(1+0.05s)(1+0.1s)(1+s)^2}$$

$$\text{Model}: \widetilde{G}_p(s) = \frac{1}{(1+s)^2}$$

$$\text{Controller}: G_c(s) = (1+s)^2 \cdot \frac{1}{(1+s/15)^3}$$

Figure 9 & 10 show the simulation result (without noise & with noise respectively).

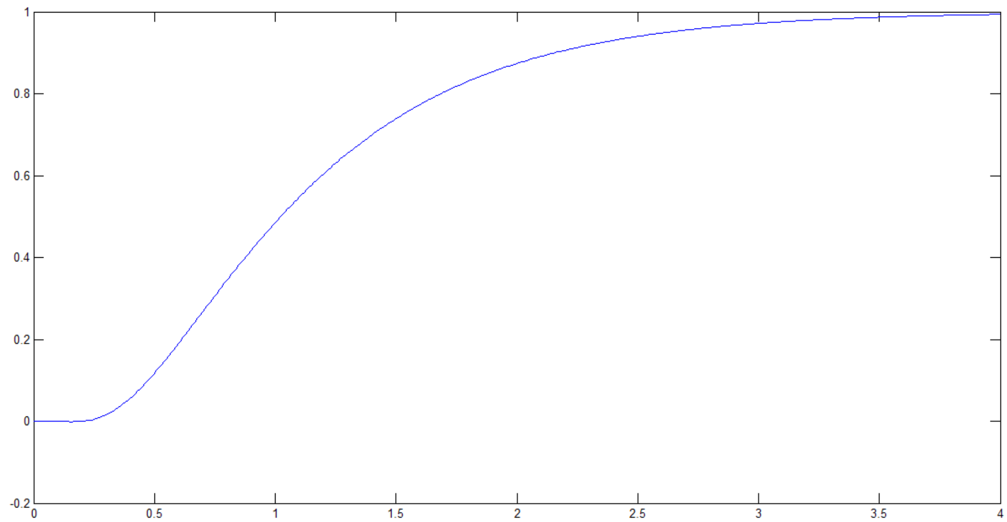

Figure 9

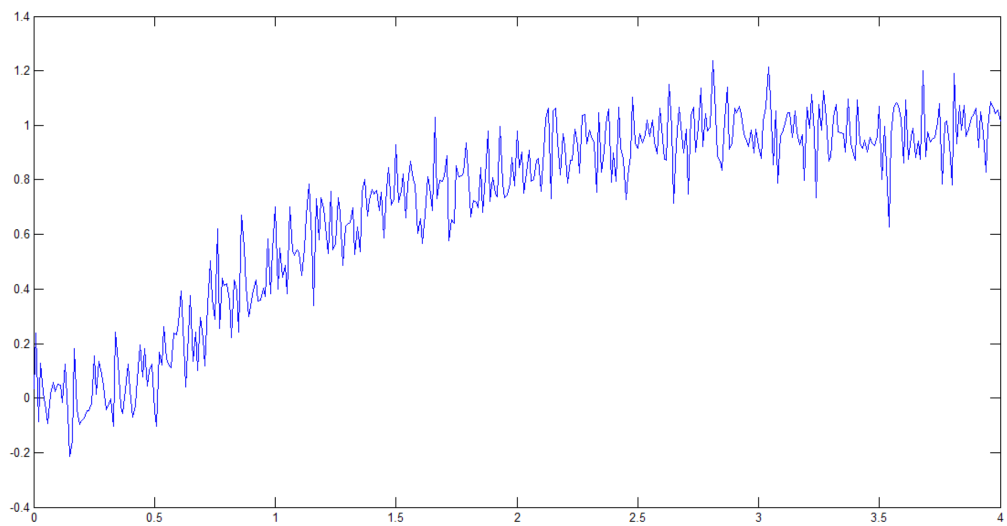

Figure 10

Conclusion

Internal Model Control seems to be a promising alternative, but further studies (& simulations) are needed to confirm its worth.

Also, the applications where IMC can be used successfully need to be identified.

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