Model Predictive control for beginners *by Anthony Rossiter*

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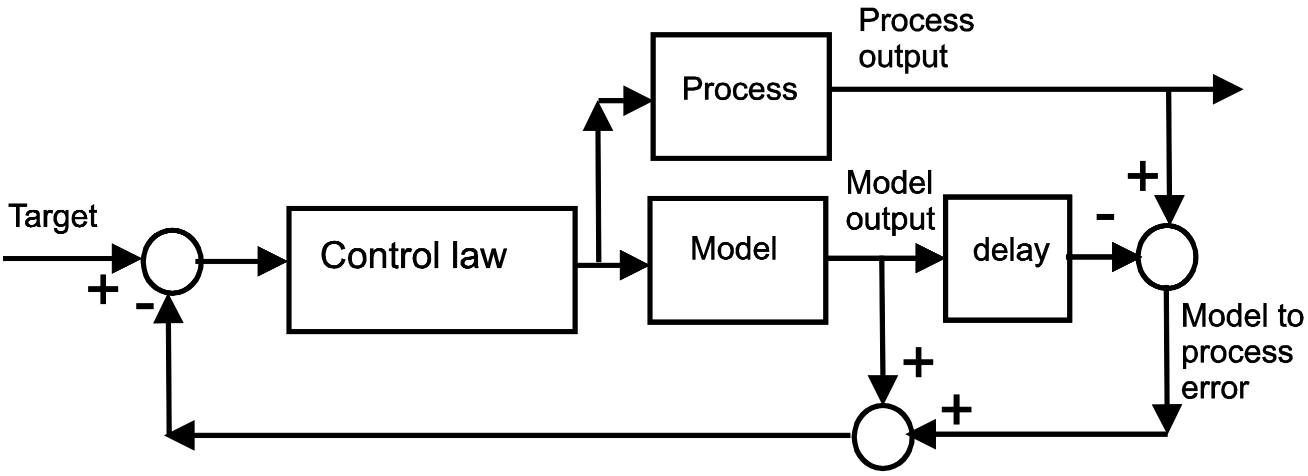
Classical control 1.3b: Smith Predictor

The previous note demonstrates that the incorporation of delays cause significant degradation in closed-loop performance if the compensator is unchanged. Nevertheless, one popular technique for handling delays while utilising classical control techniques is the so called Smith Predictor. In summary a few key observations are in order:

- A smith predictor design assumes one has an accurate model, including the delay time.
- A Smith predictor focuses on a design for controlling an exact model, with the delay removed. It is assumed that the same input trajectory is highly likely to be effective for the real process.
- Differences between the process output and delayed model output are used to correct for uncertainty.

Overview of Smith Predictor Structure



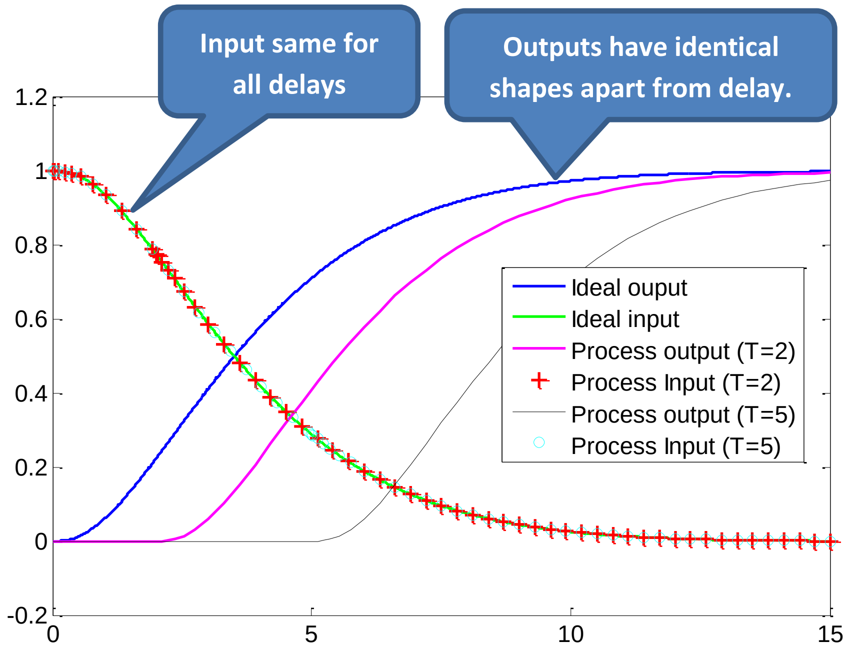
It may be clear that in the case where the model with the estimated delay is an exact match to the process, then the model to process error will be zero, so in effect the smith predictor is controlling the model. However, as the model and process have the same dynamics, the same input should result in equivalent behaviour from both.

Some examples are given next to demonstrate he efficacy of the Smith Predictor, but also the dangers!

EXAMPLE assuming no uncertainty

Consider the following system with a delay of T seconds. The impact of different values of T on the efficacy of the Smith predictor will be demonstrated. It will be assumed that the process and the model are an exact match. Two delays (T=2, T=5) are tested. The control law is set equal to one.

$$\mathrm{Pr}\,ocess = \frac{3e^{-sT}}{s(s+1)(s+4)}; \quad Model = \frac{3}{s(s+1)(s+4)}$$



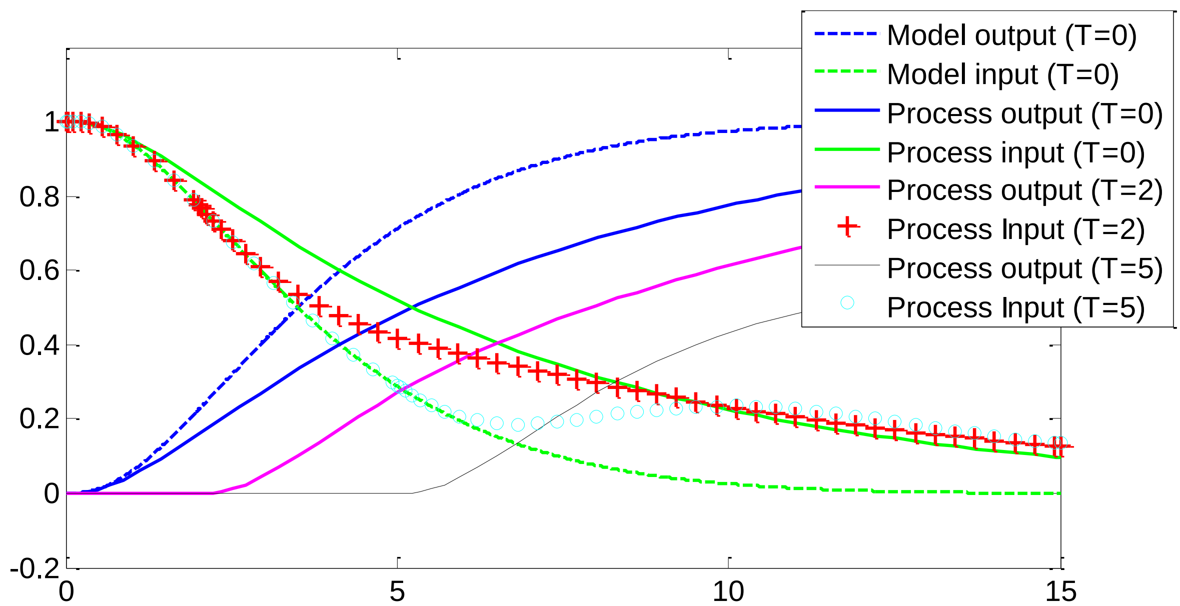
It is clear that the, in the nominal case, the Smith predictor has been effective in obtaining the same speed of response as available with the corresponding undelayed process. The input is identified immediately due to the use of the undelayed model and thus this is not affected by the actual value of delay and this means there is no delay in actuation.

EXAMPLE with parameter uncertainty

This section will give a simplistic investigation of the robustness of the Smith Predictor implementation to parameter uncertainty. For now, assume that the delay is known precisely and just experiment with changes in poles and zeros and steady-state gain.

$$\mathrm{Pr}\,ocess = \frac{3e^{-sT}}{s(s+1.4)(s+5)}; \quad Model = \frac{3}{s(s+1)(s+4)}$$

It is noted, perhaps because the process has inherently benign dynamics, that the inclusion of some parameter uncertainty, while it affects behaviour, does not cause a significant degradation or stability concerns. The process output for different lengths of delay are broadly similar, although one can see the actual closed-loop input now varies as the delay increases. [Of course this is just one example and one should not draw general conclusions from this!]

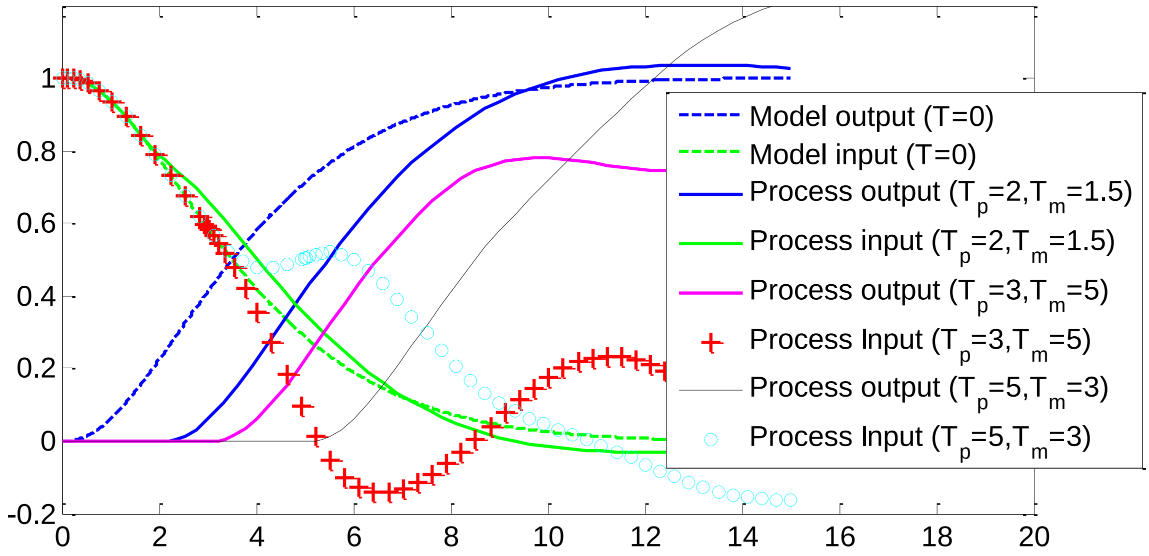


EXAMPLE with uncertainty in the dead-time

A more serious problem is likely to occur when the dead-time is not estimated correctly, that is the dead-time assumed by the model differs from the actual dead-time in the process. This section will give a simplistic investigation of the robustness of the Smith Predictor implementation to such uncertainty. Let thereal delay be T_p and the model delay be T_m.

$$\mathrm{Pr}\,ocess = \frac{3e^{-sT_p}}{s(s+1)(s+4)}; \quad Model = \frac{3}{s(s+1)(s+4)}; \; delay\ estimate = e^{-sT_m}$$

One can see that there is an obvious change in the input and output trajectories when there is uncertainty in the dead-times and indeed the oscillations occurring here are a possible indicator of the closed-loop system being close to instability.



SUMMARY: Smith predictors are an effective tool for allowing classical design techniques to be used for processes which exhibit significant dead-times and allow the user to retain a relatively high bandwidth. However, the dead-time still exists and thus any uncertainty will cause this delay to impact on the effective Nyquist diagram and one would expect the overall implementation to be far more sensitive to uncertainty than the equivalent undelayed process; consequently one should proceed with caution.