Proceeding Series of the Brazilian Society of Computational and Applied Mathematics

Pseudo Predictive Tuning Methods for PLC Embedded PID Controllers

Daniel Cavalcanti Jeronymo[1]

Federal Technological University of Paraná (UTFPR), Computer Engineering Program (COENC),

Toledo, Paraná, Brazil, Zip code: 85902-490

Federal University of Santa Catarina (UFSC), Automation and Systems Engineering Graduate

Program (PPGEAS), Florianópolis, Santa Catarina, Brazil, PO Box 476, Zip code: 88040-900

Rejane de Barros Araújo[2]

Camilo Andrés Alvaro Suárez[3]

Antonio Augusto Rodrigues Coelho[4]

Federal University of Santa Catarina (UFSC), Automation and Systems Engineering Graduate

Program (PPGEAS), Florianópolis, Santa Catarina, Brazil, PO Box 476, Zip code: 88040-900

Abstract. In this paper novel tuning settings for Proportional-Integral-Derivative (PID) controllers are proposed. These tunings are based on approximations of the generalized predictive controller (GPC) resulting in pseudo predictive PID controllers. It is possible in this way to embed industrial PID controllers as predictive controllers without hardware changes being necessary. In order to obtain this pseudo predictive tuning the PID structure is matched to the GPC structure and approximations are taken in the cases where the structures are not equivalent. A first order model implies in a PI while a second order model in a PID controller designs, respectively. Depending on which tuning is used, either set-point tracking or closed-loop characteristics is favored. Future work will include results and comparisons of the proposed tuning with other methods from literature.

Keywords. Predictive Control, PID Control, Programmable Logic Controller, Tuning Method

1 Introduction

It is frequently desired to emulate characteristics of a controller in another, however, this process is limited by mathematical formulations regarding each control structure.

[1]danielc@utfpr.edu.br
[2]rejane.barros@posgrad.ufsc.br
[3]camilo@posgrad.ufsc.br
[4]antonio.arc@ufsc.br

This is particularly true for programmable logic controllers employed in industry where the control structures are vendor dependent.

PID controllers currently dominate the market in applications of process control, accounting for more than 95% of applications [11], to which there are more than 1731 tuning methodologies [11]. Amongst these are the predictive tuning methods such as [6, 9, 10, 12, 14, 15], to name a few. However, these tunings are tailored to specific PID structures and are hard to generalize, reducing its practicality in situations where embedded control is desired, *i.e.* in a PLC.

In this paper we present six different predictive tuning methods for the PID controller. The first of these methods, called Type 1, results in a control law equivalent to GPC's and is known in literature [12], it is, however, limited to applications where both a reference and process output filters are available. In order to circumvent this limitation five other tuning methods are proposed, Types 2, 2*, 2**, 3 and 3*, which are based on approximations of Type 1's control law, hence pseudo predictive.

Of the proposed tuning methods, type 2** is of greater interest since it results in a pure PID controller, which does not need either reference or output filters.

Since these tuning methods are not tailored, and therefore not restricted to, any particular PID structure they can be applied to a wide range of PID controllers such as parallel, series and ideal. The proposed approach presents itself as a major advantage since it enables embedding PLC's with GPC's control law and introducing the benefits of model based predictive control, without any hardware change, such as: model usage; simplified tuning for processes with dead-time, non-minimum phase or unstable; sampling time considerations; desirable performance and robustness characteristics.

The paper is organized as follows. Section 2 presents the proposed tuning methods and introducing the approximations of the control law. Section 3 presents a proposal for future results and comparison of all proposed tunings and SIMC. Finally, Section 4 presents final remarks about the proposed methods and future work.

2 Pseudo Predictive PID Tuning

A family of tuning methods is proposed aiming to embed an industrial PID controller with advanced characteristics. With this objective in mind, a PI or PID controller is tuned using GPC by comparisons between the PID control law structure with GPC's. The only limitation in this project is that a first order process model tunes a PI controller whereas a second order tunes a PID controller.

GPC control law can be expanded in the form:

$$\Delta u(t) = K_{gpc}[y_r(t) - (H(z)\Delta u(t) + F(z)y(t))] \ , \tag{1}$$

where K_{gpc} is the gain vector, $H(z)$ and $F(z)$ are polynomials related to past and future control actions. Re-arranging the terms in RST form [2, 3]:

$$(1 + K_{gpc}H(z))\Delta u(t) = K_{gpc}y_r(t) - K_{gpc}F(z)y(t) \ . \tag{2}$$

Similarly for PID's control law considering two degrees of freedom (2-DOF):

DOI: 10.5540/03.2016.004.01.0055

$$\Delta u(t) = Q(z)(F_r(z)y_r(t) - F_y(z)y(t)) \ , \tag{3}$$

where $Q(z)$ is a polynomial based on proportional, integral and derivative parameters, $F_r(z)$ is the reference filter and $F_y(z)$ is the process output filter.

Equations (2) and (3) can be mapped differently depending on how the terms are arranged and if approximations are used. These different mappings result in a family of tuning methods. Therefore we present six tuning methods, of which the first is equivalent to GPC and the other five are approximations.

The reason for the existence of different tunings is the hardware limitation on PLCs. Although it's possible to find a matching identity for $Q(z)$ from GPC, it's necessary to use both the reference filter and the output filter. In the case where both are used, the controller is equivalent to GPC. In the case where only one of them is used, the resulting PID becomes an approximation of GPC. When approximations are used there are different impacts in the resulting design, such that approximations in F_r impacts set-point tracking while F_y impacts closed loop characteristics.

All proposed tunings can be found by re-writing (2) and finding identities with (3).

2.1 Type 1 - Equivalent

$$\begin{aligned}
Q(z) &= K_{gpc}F(z) \\
F_r(z) &= \frac{\sum K_{gpc}}{K_{gpc}F(z)(1+K_{gpc}H(z))} \\
F_y(z) &= \frac{1}{(1+K_{gpc}H(z))} \ .
\end{aligned} \tag{4}$$

2.2 Type 2 - Approximation in F_r

$$\begin{aligned}
Q(z) &= \frac{K_{gpc}F(z)}{1+K_{gpc}H(z)|_{z=1}} \\
F_r(z) &= \frac{\sum K_{gpc}(1+K_{gpc}H(z)|_{z=1})}{K_{gpc}F(z)(1+K_{gpc}H(z))} \\
F_y(z) &= \frac{1+K_{gpc}H(z)|_{z=1}}{1+K_{gpc}H(z)} \simeq 1 \ .
\end{aligned} \tag{5}$$

2.3 Type 2* - Approximation in F_r simplified

$$\begin{aligned} Q(z) &= \frac{K_{gpc}F(z)}{1+K_{gpc}H(z)|_{z=1}} \\ F_r(z) &= \frac{\sum K_{gpc}}{K_{gpc}F(z)} \\ F_y(z) &= \frac{1+K_{gpc}H(z)|_{z=1}}{1+K_{gpc}H(z)} \simeq 1 \;. \end{aligned} \tag{6}$$

2.4 Type 2** - Approximation in F_r further simplified

$$\begin{aligned} Q(z) &= \frac{K_{gpc}F(z)}{1+K_{gpc}H(z)|_{z=1}} \\ F_r(z) &= \frac{\sum K_{gpc}}{K_{gpc}F(z)|_{z=1}} = 1^{\dagger} \\ F_y(z) &= \frac{1+K_{gpc}H(z)|_{z=1}}{1+K_{gpc}H(z)} \simeq 1 \;. \end{aligned} \tag{7}$$

†see Section 2.7 for explanation.

2.5 Type 3 - Approximation in F_y

$$\begin{aligned} Q(z) &= \frac{\sum K_{gpc}}{1+K_{gpc}H(z)|_{z=1}} \\ F_r(z) &= \frac{1+K_{gpc}H(z)|_{z=1}}{1+K_{gpc}H(z)} \simeq 1 \\ F_y(z) &= \frac{K_{gpc}F(z)(1+K_{gpc}H(z)|_{z=1})}{\sum K_{gpc}(1+K_{gpc}H(z))} \;. \end{aligned} \tag{8}$$

2.6 Type 3* - Approximation in F_y simplified

$$\begin{aligned} Q(z) &= \frac{\sum K_{gpc}}{1+K_{gpc}H(z)|_{z=1}} \\ F_r(z) &= \frac{1+K_{gpc}H(z)|_{z=1}}{1+K_{gpc}H(z)} \simeq 1 \\ F_y(z) &= \frac{K_{gpc}F(z)}{\sum K_{gpc}} \;. \end{aligned} \tag{9}$$

2.7 Observations

Tuning type 1 results in a PID equivalent to GPC, described in literature by [12], however it is necessary for this case to adjust both the reference filter and output filter in the PID controller.

Type 2 and type 3 methods are obtained by using the approximation $z = 1$ on particular polynomials in order to obtain a constant, this causes a loss on dynamics but preserves the static components [4, 7].

Tuning types 2, 2* and 2** use approximations on the reference filter, favoring set-point tracking characteristics while compromising robustness and load disturbance rejection, resulting in agressive control actions. Tuning types 3 and 3* employ approximations on the output filter thus favoring robustness and disturbance rejection, compromising set-point tracking performance, leading to conservative control actions.

Although originating from different approaches, tunings 2* and 3* result in the same closed loop transfer function. The advantage of these simplified tunings is an easier implementation, with lower computational cost and they provide a compromise between performance and robustness.

Tuning type 2** is of greater practical application than all the others since the resulting reference filter is a unitary constant and as such the control law matches a pure PID. This enables a simple PID controller, without a reference filter or an output filter, to be tuned by GPC without absolutely any hardware change. The reference filter results in a unitary constant given the nature of $F(z)$, we leave the conclusion of this up to the reader.

Steady state characteristics are preserved by the approximation $1 + K_{gpc}H(z)|_{z=1}$, at the compromise of ignoring dynamics. The approximation error can be calculated by $K_{gpc}(H(z)-H(1))$, therefore there is a direct relationship between the approximation error and GPC's control gain. Thus aggressive projects will result in a greater approximation error while conservative control laws obtain a smaller error, regarding dynamics.

Using a first order model results in a PI controller while a second order model results in a PID controller. Therefore the only limitation regarding this proposed family of tuning methods is the model order. There aren't any limitation regarding model characteristics or GPC parameters, making these tuning approaches a good alternative to processes with long dead-time, non-minimum phase zeros, integrators or unstable poles.

We do note, however, the proposed tuning approaches are more design intensive than other, simpler, tuning rules such as [1, 13, 16].

It is necessary to stress: i) these tunings are consistent for a wide set of PID structures since they are based on the $Q(z)$ polynomial; ii) sampling time is a controller design parameter which is naturally taken into account by GPC and, as such, is embedded in the proposed tunings.

3 CLP Application Results

In future work, regarding practical results using the embedded controller PLC300 by WEG will be used in a HIL scheme where the controlled process is stable and non-minimum phase. The process' transfer function, from [13], is given by:

DOI: 10.5540/03.2016.004.01.0055

$$G(s) = \frac{(-0.3s+1)(0.08s+1)}{(2s+1)(s+1)(0.4s+1)(0.2s+1)(0.05s+1)^3} \tag{10}$$

and the process model:

$$G_n(s) = \frac{k}{(\tau_1 s+1)(\tau_2 s+1)} e^{-\theta s} \tag{11}$$

where $k = 1$, $\tau_1 = 2$, $\tau_2 = 1.2$ and $\theta = 0.77$.

There is a vast literature regarding parameter choices for model based predictive controllers, see [5] for a comprehensive review, however, we suggest the following simple choice: $N_u = N_y = \lceil N/T_s \rceil$ and $\lambda = \lambda_c k^2$. Where N is the settling time and λ_c is a free parameter which regulates the desired control aggressiveness, similar to trial and error GPC tunings such as [8].

Aiming to exaggerate SIMC's limitations, a high sampling time $T_s = 1$ will be considered. GPC parameters are given by $N = 15$ and $lambda_c = 20$. The resulting control laws will also be presented.

Several metrics are used to evaluate the proposed tunings. Regarding performance, which reflects GPC's cost function, integral squared error (ISE) and integral squared variation control (ITVC). For robustness the indices gain margin (GM), phase margin (PM) and maximum sensitivity (Ms).

These possible results should demonstrate if the approximations do not deviate much from standard GPC, given by tuning Type 1. In this context of high sample time, it's expected for SIMC to fail adequate control of the process, demonstrating the advantage of the proposed method.

4 Discussion and final remarks

In this paper a set of tuning methods was presented with direct application to embedded PID controllers. Future results will demonstrating the proposed tunings, based on approximations, do not diverge greatly from standard GPC. Furthermore, the proposed tunings should be capable of dealing with an improper choice of settling time.

These results should indicate this as a promising approach for tuning PID controllers in PLCs. Future work will also focus on gathering results for other process classes, considering a variety of sampling times, and comparisons with more tuning approaches from literature.

References

[1] K.J. Astrom and T. Hagglund. Revisiting the Ziegler-Nichols step response method for PID control. *Journal of Process Control*, 14(6):635–650, 2004.

[2] K.J. Astrom and B. Wittenmark. *Computer-Controlled Systems: Theory and Design, Third Edition*. Dover Books on Electrical Engineering Series. Dover Publications, New York, USA, 2011.

DOI: 10.5540/03.2016.004.01.0055

[3] A. A. R. Coelho, R. B. Araújo, and A. S. Silveira. Steady-state tracking properties for the generalized minimum variance controller: A review, proportional-integral-derivative tuning, and applications. *Industrial & Engineering Chemistry Research*, 53(4):1470–1477, 2014.

[4] E. B. Dahlin. Designing and tuning digital controllers. *Instruments and Control Systems*, 41(6):77–83,87–91, 1968.

[5] J. L. Garriga and M. Soroush. Model predictive control tuning methods: A review. *Industrial & Engineering Chemistry Research*, 49(8):3505–3515, 2010.

[6] MR. Katebi and M.H. Moradi. Predictive PID controllers. *IEE Proceedings - Control Theory and Applications*, 148(6):478–487, 2001.

[7] J. R. Leigh. *Applied Digital Control.* Dover Publications, Mineola, USA, 2009.

[8] A. R. McIntosh, S. L. Shah, and D. G. Fisher. Analysis and tuning of adaptive generalized predictive control. *Canadian Journal of Chemical Engineering*, 69:97, 1991.

[9] R.M. Miller, S.L. Shah, R.K. Wood, and E.K. Kwok. Predictive PID. *ISA Transactions*, 38(1):11–23, 1999.

[10] M.H. Moradi, M.A. Johnson, and M.R. Katebi. Predictive pid control. In M.A. Johnson and M.H. Moradi, editors, *PID Control – New Identification and Design Methods*, pages 473–524. Springer, London,UK, 2005.

[11] A. O'Dwyer. *Handbook of Pi and PID Controller Tunning Rules.* Imperial College Press, London, UK, 2009.

[12] T. Sato. Predictive control approaches for pid control design. In R. Vilanova and A. Visioli, editors, *PID Control in the Third Millennium: Lessons Learned and New Approaches*, pages 553–595. Springer, London,UK, 2012.

[13] S. Skogestad. Simple analytic rules for model reduction and pid controller tuning. *Journal of process control*, 13(4):291–309, 2003.

[14] K.K. Tan, S.N. Huang, and T.H. Lee. Development of a GPC-based PID controller for unstable systems with deadtime. *ISA Transactions*, 39(1):57–70, 2000.

[15] K.K. Tan, T.H. Lee, and F.M. Leu. Predictive PI versus smith control for dead-time compensation. *ISA Transactions*, 40(1):17–29, 2001.

[16] A. Visioli. Optimal tuning of pid controllers for integral and unstable processes. *IEEE Proceedings on Control Theory and Applications*, 148(2):180–184, 2001.

DOI: 10.5540/03.2016.004.01.0055