RelaxC Controller Improves and Maintains Process Control

John Masse
APPEDGE

***Abstract* - With its ad hoc algorithmic structure, RelaxC frees itself from hard mathematical difficulties as well as from a tedious and imprecise process modeling to guarantee robust control with an easy adjustment; i.e., without any calculation beforehand.**

Index Terms – PLC process control, adaptive control, industrial manufacturing, SCADA.

NEXT GENERATION PROCESS CONTROL: RELAXC

The industrial controller RelaxC is an innovative and unique method of stochastic gradient descent on time evolving systems. This article explains how RelaxC works and shows interesting configurations for using RelaxC.

This controller has been successfully tested on complex industrial plants. By its performance, RelaxC is a great alternative to advanced or classical control methods such as predictive functional control (PFC), model predictive control (MPC), internal model control (IMC), LQG, LQR, proportional-integral-derivative (PID), etc., which struggle or fail in the control of complex systems of the following types: nonlinear, with delay, with non-minimal phase, and with control constraints.

With its ad hoc algorithmic structure, RelaxC frees itself from these hard mathematical difficulties as well as from a tedious and imprecise process modeling to guarantee robust control with an easy adjustment, i.e., without any calculation beforehand.

Consequently, it allows manufacturers to reduce their design, commissioning, and maintenance costs while keeping control of its processes and increasing their efficiency.

In addition, with low CPU load (less than 10 arithmetic operations), it runs on all programmable logic controller (PLC)/supervisory control and data acquisition (SCADA) software platforms such as Straton PLC, EcoStruxure Control Expert, EcoStruxure Automation Expert, Zenon Copa-Data, or engineering simulation tools (Simulink, Python, Ecosim, Scicos, R language, etc.) and is supported by nano electronic control units (ECUs) (PIC, Arduino, Raspberry, etc.).

DESCRIPTION OF RELAXC

$$\begin{cases} \boldsymbol{u_{n+1} = \Re_{(u_n,\tau_{re})} + k_s(\tau_g * \dot{e} + e)} \\ \boldsymbol{k_s = \frac{1}{v*\tau_g*\left(\frac{t_d}{\tau_{re}}+1\right)}\ , e = y_{g-}y_m} \end{cases}$$

RelaxC is a recurrence equation. Figure 1 shows its functional representation. The model or process is represented by the "plant" whose input u_m=$U_{Relaxc} = u_{n+1}$ and its output $y_m = PV$ or "process variable."

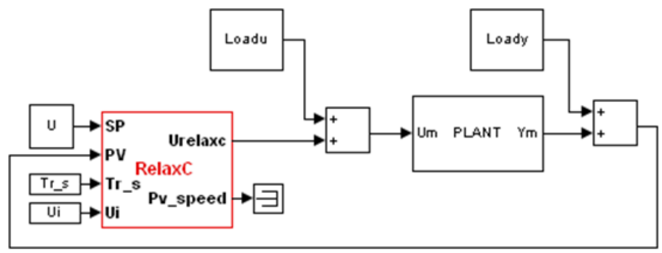

FIGURE I
FUNCTIONAL REPRESENTATION OF RELAXC

RelaxC build, via a trajectory generating function, which is a mathematical concept introduced by the RelaxC methodology, the so-called reference trajectory (here of the first order), named y_g and of time constant τ_g, which simultaneously and securely leads the trajectories of y_m *and* y'_m towards y_g *et* y'_g.

The operation of RelaxC is to determine $\boldsymbol{u_n}$ at each iteration to find the extremums $e = y_{g-}y_m = 0$ and $\dot{e} = \dot{y}_{g-}\dot{y}_m = 0$ where error convergence speed is controlled by the gain $k_s = \frac{1}{v*\tau_g*\left(\frac{t_d}{\tau_{re}}+1\right)}$. This gain depends on the physical characteristics of the process, which are the pure delay t_d, the absolute value of its maximum speed $v = v_m$, and finally, the time constant τ_{re} of the function $\Re_{(.)}$, which characterizes the reactivity or relaxation time of the process to reach its maximum speed.

RelaxC tuning. On a real system, identification is done online and graphically, whatever the process (stable, integrating, unstable), using a step response or any other method. The family of stable systems is represented by $H_m = \frac{k_{mp}e^{-t_d s}(a0+a1*s+\cdots s^q)}{(1+b_1 s+b_2 s^2+\cdots s^p)}, p \geq q.$

In Figure 2, $v = v_m, t_{lag}, t_m$ is measured to calculate 3 normalization coefficients with the following relations: $\tau_{re} = \frac{t_d}{3} + t_{lag}$, $\tau_g = \min(t_m, 3 * t_{re})$, and k_s. The realization of autotuning is direct.

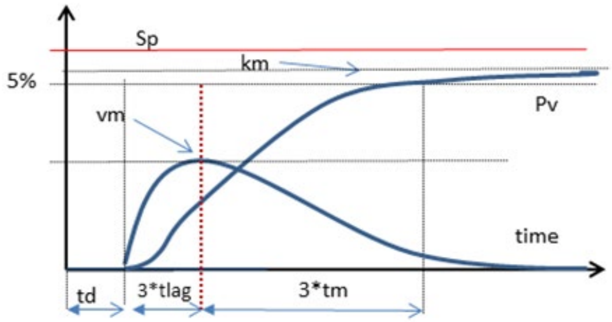

FIGURE 2
THE GRAPH SHOWS THREE CALCULATED NORMALIZATION COEFFICIENTS

RelaxC: a green controller. We wish to control the model $\frac{Y_m}{U_m} = \mathbf{H}_m = \frac{2*e^{-0.8s}}{(s+1)(s+0.1)}$ with the following constraints: fast setpoint tracking without overshoot with active rejection of intervening disturbances on the input (Load U) and output (Load Y) (Figure 1).

The physical coefficients of RelaxC are determined from the open loop response (Figure 3): $t_d = 0.8$ $v_m = 1.55$, $t_m = (33 - 3.5)/3 = 9.33$ and $t_{lag} = \frac{(3.5 - t_d)}{3} = 0.9$. We use $t_{lag} = 1.4$ to slow down RelaxC and move toward the same response time as the PID setting. The result is: $k_s = 0.09$ with $\tau_{re} = \frac{t_d}{3} + t_{lag} = 1.7$ and $\tau_g = \min(t_m, 3 * t_{re}) = 5.2$. Note that the tuning is almost instant.

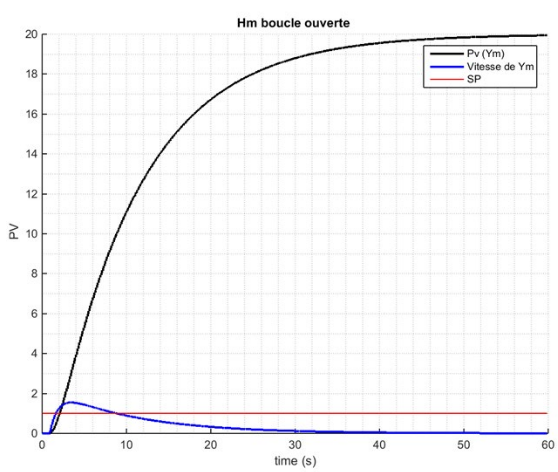

FIGURE 3
WHEN APPLIED CORRECTLY, THE TUNING IS ALMOST INSTANT

To find mathematical coefficients of the PID(z), we use the tool "Tuner Simulink" (a model is necessary) that finds: $K_p = 0.095$, $K_i = 0.0082$, $K_d = 0.1$ N=10 for a sampling time of $T_e = 100\ ms$.

RelaxC setting predicts the response time in the closed loop: $(\tau_{re} + \tau_g) * 3 = 20\ s$, and to reach it, the initial command is: $u_m(1) = k_s * SP = 0.09$; that's 13 times less energy than the PID one: $u_{pid} = 1.2$ (Figure 4).

To compare the two controllers, we use the integral of the absolute error term (IAE): $IAE = \int |e|$. The yellow color (Figure 4) represents the control difference between RelaxC and PID, which is a loss of control of more than 80 percent of the PID to follow the setpoint in the presence of disturbances.

Knowing at least 90 percent of industrial processes are controlled by PIDs—often poorly adjusted—and any deviation from the setpoint increases production waste or energy consumption as well as premature wear of production tools, RelaxC is the solution to achieve substantial savings: It is a "green controller," as Schneider Electric has found on the regulation of a blast furnace in the Isère region of France.

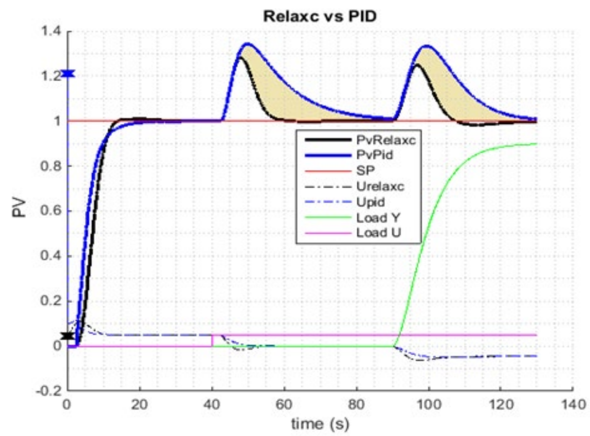

FIGURE 4
RELAXC SETTING PREDICTS THE RESPONSE TIME IN CLOSED LOOP: $(\boldsymbol{\tau_{re}} + \boldsymbol{\tau_g}) * \mathbf{3} = \mathbf{20}\ \boldsymbol{s}$.

RelaxC: an optimal controller. In robotics, in piloting or to solve a problem of "rendezvous," it is necessary to connect two points to find a feasible trajectory in a minimum time with a smooth docking.

The theory of optimal control shows that the solution is a bang bang control (an on-off controller, or a feedback controller that switches abruptly between two states), where the switching times are sought. Let us apply RelaxC to a triple integrator $\boldsymbol{Y_m} = \frac{\mathbf{1}}{\boldsymbol{s^3}} \boldsymbol{U_m}$ with $\boldsymbol{U_m} \in [-\mathbf{1}, \mathbf{1}]$ constraint. Used in cascade structure (Figure 5): Loop on speed and position, RelaxC finds online a Bang Bang command (Blue) to reach the setpoint without exceeding it ($\boldsymbol{S_p} = \mathbf{1}$) (Figure 6). The disturbance also is actively rejected. The setpoint sign changes indicate the desired switching times.

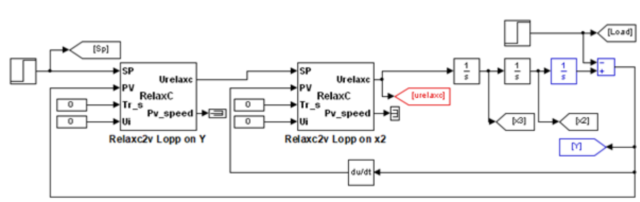

FIGURE 5
CASCADE STRUCTURE

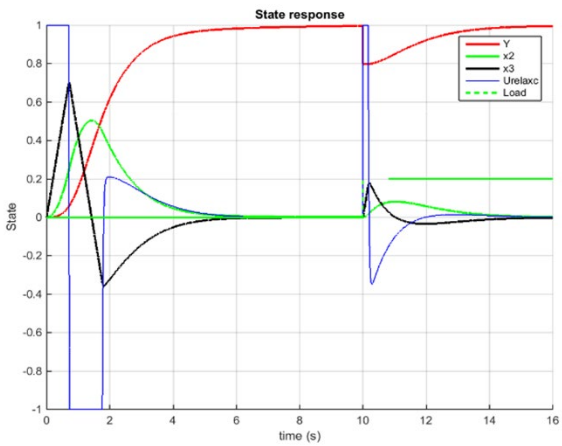

FIGURE 6
RELAXC FINDS A BANG BANG COMMAND (BLUE) TO REACH THE SETPOINT WITHOUT EXCEEDING IT

PURSUING SMART SCADA

Maximizing energy efficiency and increasing the profitability of processes depends a high-performance control law and, in terms of supervision and real-time decision support, the use of fast and efficient algorithms on noisy signals. Rare are the algorithms that meet these requirements and even less with a predictable convergence time. RelaxC is the right candidate.

The development of a smart SCADA system becomes possible by embedding RelaxC as a data mining tool for the search for extreme or reconstruction of signals and indicators.

RelaxC can be used in different ways to solve complex problems that are often inaccessible because of their computational complexity without advanced algorithmic expertise.

For example, the configuration in Figure 7 is a state observer/reconstructor built from a single measurement (the multiple-input multiple-output [MIMO] case is possible). RelaxC becomes a serious competitor to the complexity of the extended Kalman filter. Unlike the latter, it is not necessary to compute a Jacobian or to invert a matrix, and its setting is easily accessible to all for similar or better performances.

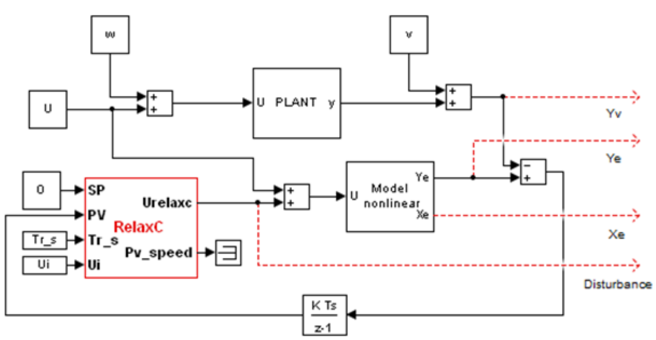

FIGURE 7
STATE OBSERVER/RECONSTRUCTOR BUILT FROM A SINGLE MEASUREMENT

Figure 8 transforms RelaxC into a signal filter $\mathcal{F}_{filtre}(Y(t)) = \int Urelaxc\, dt$ and simultaneously in time derivation operator where $\frac{dY(t)}{dt} = Urelaxc$. Note that the derivation action is performed by integration of the error. A cascading sequence allows obtaining higher orders of the derivative.

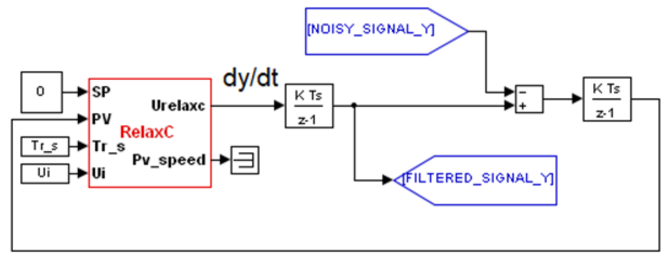

FIGURE 8
DERIVATION ACTION IS PERFORMED BY INTEGRATION OF THE ERROR. A CASCADING SEQUENCE ALLOWS OBTAINING HIGHER ORDERS OF THE DERIVATIVE

Let's apply it to a noisy signal such as radar, GPS, accelerometer, acoustic, or stock price.

$$\begin{cases} y(t) = b(t) - 0.75 \; if \; t < 0.5 \\ y(t) = tanh(t-1) + e^{-\left(\frac{t}{1.2}\right)} \sin(6t+\pi) + \mathrm{b(t)} \end{cases}$$

with b(t) a noise of 10^{-9} and $Te = 10^{-5}s$. Results are excellent despite the difficulty related to the discontinuity of the derivative at t=0.5s. The filtered signal is superimposed exactly without delay on the reference signal (Figure 9) as well as the derivative (Figure 10).

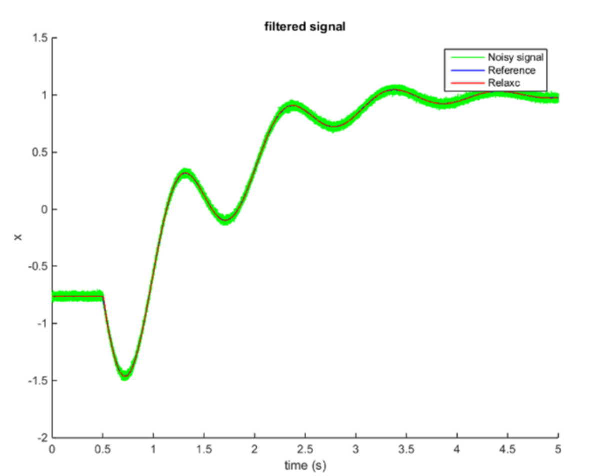

FIGURE 9
THE FILTERED REFERENCE SIGNAL

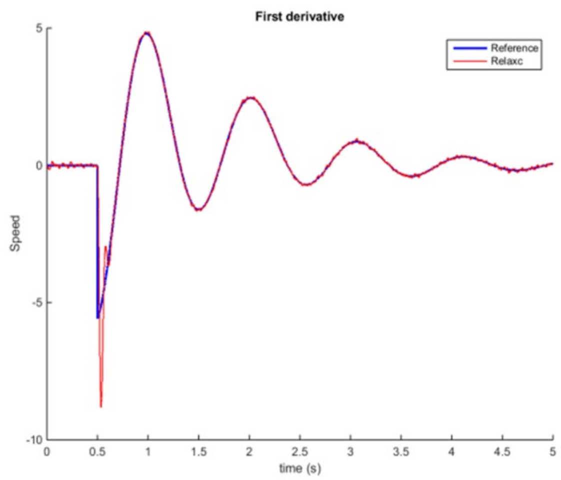

FIGURE 10
THE FIRST DERIVATIVE

RelaxC and SoftPLC. With its small memory footprint, RelaxC can be easily encapsulated in engineering software, runtimes, and SoftPLC to the IEC 61131-3 standard with languages (ST, FBD, SFC, LD, and IL) for two main reasons:

1. RelaxC is a stochastic gradient descent on a time varying parameter, so we must keep the last state and the last time used whatever the process dead time.
2. Unlike other advanced control methods, the RelaxC trajectory reference mechanism allows—even if the time cycle is not constant (interruptions, events, or communication delays (Ethernet, Wi-Fi)—to continue to keep process control as long as $T_{cycle} < \frac{t_g}{3}$.

BENCHMARK RELAXC ON DATA/PROCESS

As the easiest is to try it, we have built an industrial "toolbox RelaxC Plug & Control" where RelaxC is running. Users can interact with it via Modbus or OPC UA or EIP (other channels can be built as well*)*. As such, send the setpoint and process variable and the optimization module will provide you the right output.

FINAL THOUGHTS

RelaxC is the Swiss Army Knife for decision-makers, engineers, technicians, and students who wish to accelerate their projects by obtaining maximum performance for their processes, whatever their sector of activity: Drone, avionics, marine, water treatment, biology, energy management, and production (building, oven), machine tools, engines, machinery, etc.

RelaxC frees industrial innovation from mathematical constraints while simplifying its implementation. The best way to know is to try it: relaxc@appedge.com or to participate in the discovery and training sessions of "RelaxC: Plug and control" organized by ISA France.

ACKNOWLEDGEMENTS

Thank you to M. Chandeveau (process control expert at Shell), JP.Hauet (President ISA France), and Steve Mustard (President ISA World) for their help and advice.

AUTHOR INFORMATION

John Masse (john.masse@appedge.com) dedicated many years to innovation in the field of process control, simulation, optimization applied to automative and space industry. Founder of APPEDGE, developed a next generation process control which is extraordinarily powerful, faster commissioning. RelaxC is a real alternative to the complexity and difficulty of tuning conventional controllers.

RELATED ARTICLES AND LINKS

[1] "5 Steps to Select a Predictive Analytics Solution." https://www.automation.com/en-US/Articles/June-2021/5-Steps-Select-Predictive-Analytics-Solution

[2] "Advancing Automation Requires an Evolution in Data Management." https://www.automation.com/en-US/Articles/September-2021/Advancing-Automation-Evolution-Data-management

[3] "Digital Twins Enable the Autonomous Paper Mill." https://www.automation.com/en-US/Articles/September-2021/Digital-Twins-Enable-Autonomous-Paper-Mill

[4] "RelaxC Documentation References and Trial Versions." https://www.researchgate.net/publication/344219560_Relaxc_Bibliography_v2