1998-01-01

The gain scheduled piece-wise adaptive digital control of a pH process

Eugene O'Shaughnessy
Technological University Dublin

Aidan O'Dwyer
Technological University Dublin, aidan.odwyer@tudublin.ie

From: Proceedings of the *International Postgraduate Student Research Conference*, Dublin Institute of Technology, Dublin, Ireland, November 1998.

Gain scheduled PI control of a pH process

E. O'Shaughnessy, A. O'Dwyer [1]
School of Control Systems and Electrical Engineering,
Dublin Institute of Technology,
Kevin St., Dublin 8.

Phone: 353-1-4024875
E-mail: aidan.odwyer@dit.ie

Abstract: *The compensation of a pH process is complicated by the non-linear nature of the process titration curve and the significant time delays that typically exist in such processes. This paper will propose the use of a gain scheduled piecewise adaptive PI controller to compensate the process. A pilot plant is controlled, with the control algorithm implemented on a programmable controller. SCADA software displays and trends the plant and controller signals.*

1. Introduction

The pH loop is difficult to control as (1) the response of pH to reagent addition tends to be non-linear (2) the sensitivity of pH to reagent addition in the vicinity of a pH set-point of 7 tends to be high, with low sensitivity at the extremities of the pH scale and (3) the process titration curve changes as the incoming effluent flow strength changes.

This paper will consider the control of pH on the PROCON pH process control trainer 38 series, supplied by Feedback Instruments Ltd.. A labelled diagram of the device is provided in Figure 1. Effluent of pH 10 is continuously fed into a reaction vessel from a holding tank via a manual control valve and variable area flowmeter. The reagent of pH 4 is fed into the reaction vessel from its holding tank via a manual control valve, variable area flowmeter, solonoid valve and servo valve; the controller to be designed operates the linear servo valve to allow the reagent to be mixed with the effluent to achieve a desired pH level, measured by a pH probe. The resulting liquid exits to a treated fluid tank. The servovalve operates over a 4-20mA range.

2. Process characterisation and controller design

The pH probe converts the concentration of hydrogen ions [H+] in the solution (which gives an indication of the pH) to potential difference; the probe consists of a reference electrode and a liquid junction. The potential difference is given by

$$E = 59.16 \log[H+] - Eref - Ej \text{ [mV]}$$

with Eref = potential of reference cell and Ej = potential of liquid junction.

The pH of the solution is sensitive to variations in surrounding environmental temperature. A measurement time delay exists between the ions in the process solution and those at the surface of the electrode, due to the coating of the electrode; typically, a 1mm coating produces a time delay of several minutes. This time delay is added to the variable time delay of the process, which arises due to the solution head in the reaction vessel.

It is desired to design a controller to achieve a pH of 7.0 in the reaction tank. The overall process time delay in this tank is of interest; the other main parameter of interest for controller design is the gain of the process. This is determined from the titration curve, which

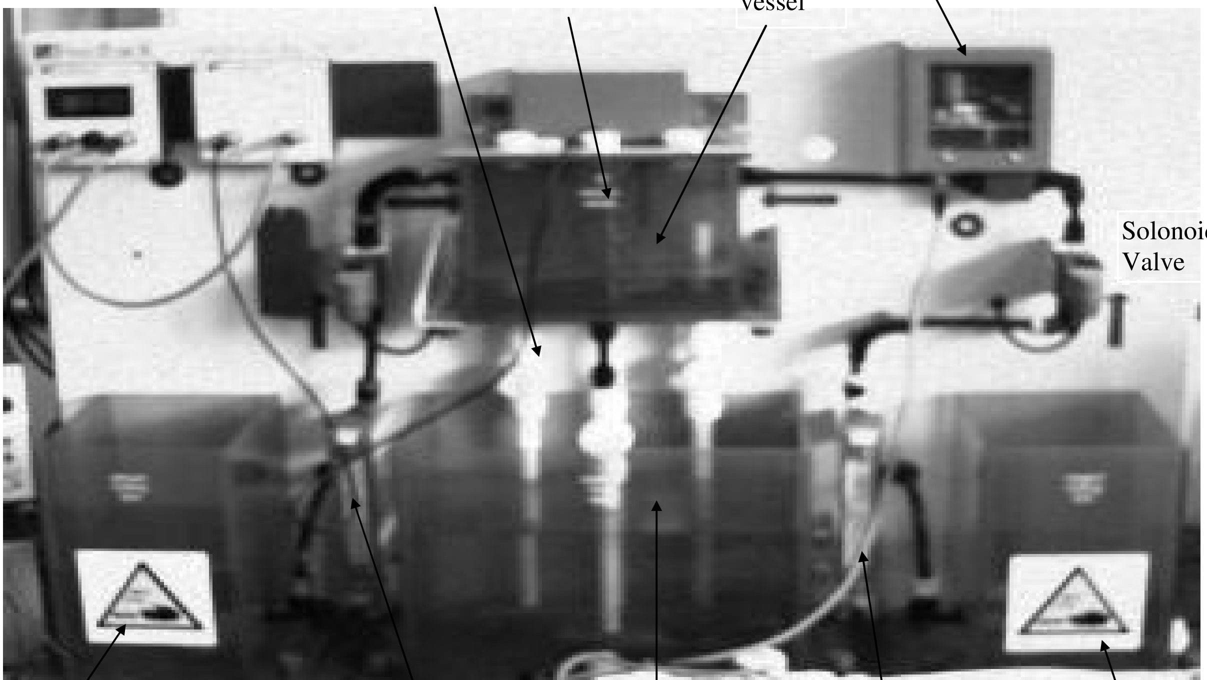
[1] Author to whom correspondence should be sent

From: Proceedings of the *International Postgraduate Student Research Conference*, Dublin Institute of Technology, Dublin, Ireland, November 1998.

may be found by incrementally adding small amounts of an acid or base chemical solution to the process solution and noting the pH of the result at each increment. The resulting titration curve is non-linear in nature. It may be approximated by five linear regions, two of which have a low gain; two more regions have a higher gain, with the region from a pH of 5.5 to 8.5, approximately, having the highest gain. Further details of the modelling are provided in the poster.

The non-linear nature of the process motivated the use of a gain scheduled PI controller. The initial controller parameters were determined using the robust design approach of Fruehauf *et al*. [1]. The controller gain was eventually chosen so that the product of this gain and the slope of the process titration curve is held approximately constant. A possible alternative to the use of the PI controller is the Smith predictor [2]; however, the fixed Smith predictor relies on an accurate plant model. The process characteristic tends to change with time.

Figure 1:



3. Implementation issues

The gain scheduled controller is implemented on a programmable controller (PLC). The analogue input from the pH electrode is connected to the analogue input card on the PLC with the analogue output signal to the control valve being connected from the PLC to the process interface. A connection interface unit was designed and built to facilitate switching of the field devices and to convert the 4-20mA current signal to a 0-10V signal for use in plotting responses on an XY recorder. A Mitsubishi FX-2C PLC was selected.

SCADA (Supervisory Control And Data Acquisition) software displays and trends the plant and controller signals on a personal computer (PC); a RS-232 link exists between the

PLC and the PC to enable the software to communicate with the PLC registers and internal flags. The RS-232 cable is connected to COM2 port on the PC and is converted to RS-422 format via a separate unit on the PLC rack. SCADA software aids data acquisition (i.e. the ability to retrieve data from the pH process, to direct communications with I/O devices on the plant and to interface to the I/O devices via I/O drivers) and data management (the ability to process and manipulate acquired data, to graphically display this data, to supervise control and to provide historical alarm data). Six SCADA screens were chosen to display the relevant data; these screens show a main menu, a plant schematic, an adaptive control window, a manual control window, plant requirements and a Microsoft EXCEL master copy window. Further details will be provided in the poster.

4. Results

The process parameters were determined from a step test performed on the plant. The gain and time delay of the process were determined. The tuning rule of Fruehauf *et al.* [1] was used to determine the integral time of 30s; the controller gain chosen varies from 10 (for pH of 5.5 to 8.5) to 50 (for pH of 5.0 to 5.5 and for pH of 8.5 to 9.0) to 250 (when the pH is below 5.0 and above 9.0).

One representative implementation result is shown in Figure 2; the desired pH is stepped from 7.5 to 7.0 and subsequently from 7.0 to 7.5. Such a test does not involve gain scheduling in the controller. It is interesting to note that the closed loop response is different in both directions, due to the open overflow valve on the reaction tank, which is located close to were the effluent enters the tank (Figure 1); thus, this open valve tends to drain off the effluent as it is added to the vessel. Therefore, the solution is less alkaline than expected and the controller closes off the reagent flow to allow an increase in pH. This controller behaviour continues until the reagent addition is so small that the process solution pH increases quickly, to be corrected by opening the control valve to allow in more reagent which reduces the solution pH. On the other hand, the step down response is clearly much better, as the reagent has time to be mixed before exiting out of the overflow pipe. Thus, a possible refinement in the approach would be to estimate the process parameters in both directions and introduce an additional gain scheduling component.

A further implementation result is shown in Figure 3; the desired pH is stepped from 7.0 to 5.0. Gain scheduling is implemented. The response shows the solution pH moving through the three separate regions of the titration curve. The pH saturates (with the original controller gain of 10) temporarily around pH 5.5 until the new controller gain (of 50) is switched in to bring it to the first setpoint of pH 5.0. Then to reach the next setpoint of pH 4.5, the controller gain is switched to its maximum value (of 250) and the pH tracks the new setpoint. The controller output saturates when the controller gain equals 250 and increasing the gain further will have negligible effect on the response.

From: Proceedings of the *International Postgraduate Student Research Conference*, Dublin Institute of Technology, Dublin, Ireland, November 1998.

Figure 2: Closed loop response

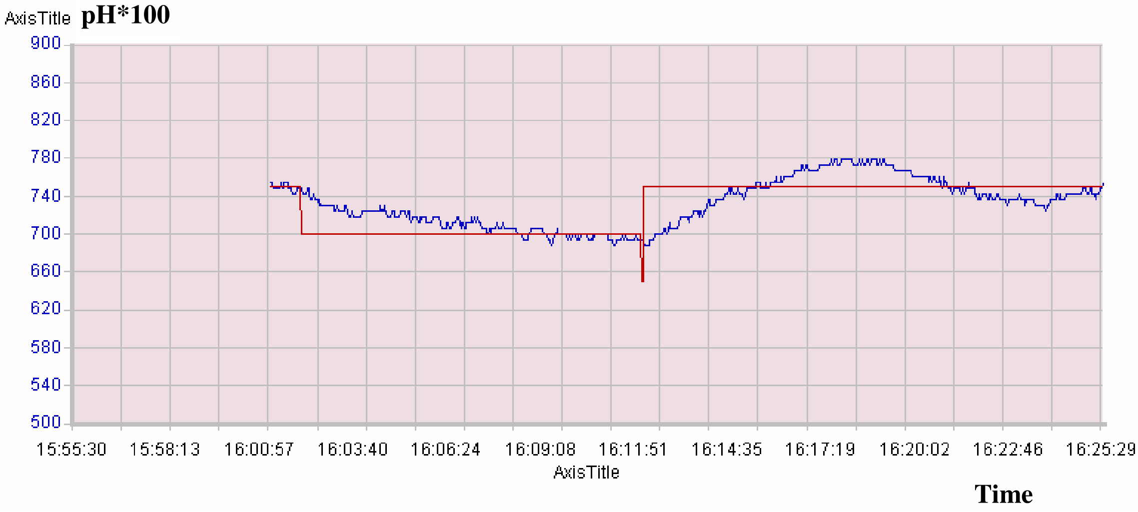
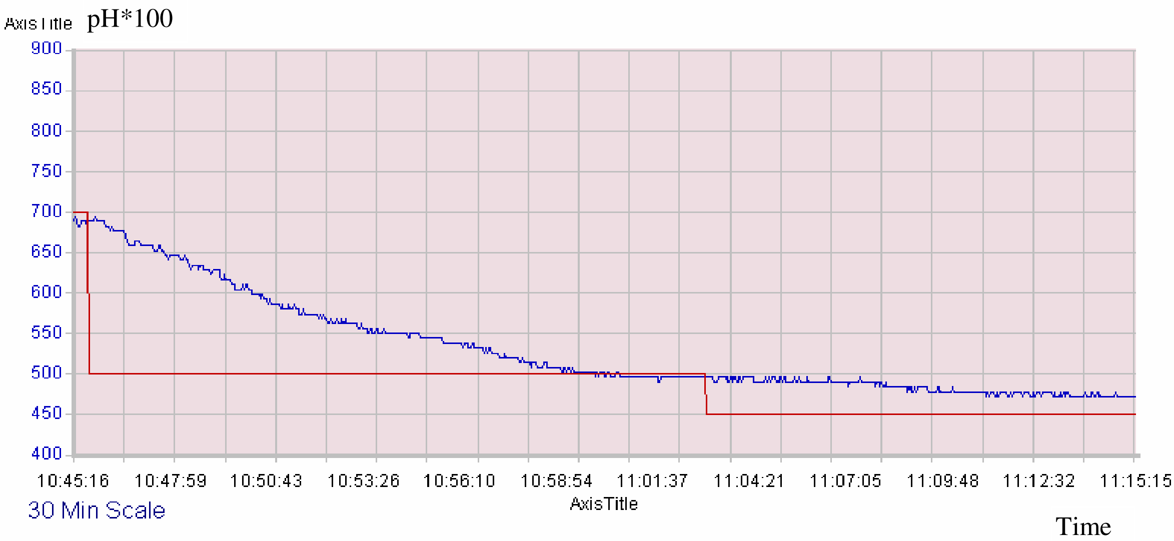


Figure 3: Closed loop response - gain scheduled controller



5. Conclusions

The gain scheduling PI controller is a cost effective and efficient method of controlling the process. A significant advantage over an alternative controller structure is the ease of implementation of the PI controller in the PLC environment. The interface to the SCADA software facilitated the design of user friendly control and information screens (which will be demonstrated in the poster). The implementation of a facility to import information from the SCADA package to the Microsoft EXCEL environment allowed the collation of master control records.

A number of possibilities for further work are as follows:

(1) Introduction of an extra pH electrode. In wastewater treatment, the pH of the incoming solution will change with temperature and with the time of day. The addition of an electrode in the effluent supply path would provide extra information for the controller for adaptation purposes, with the amount of reagent addition being contingent on the strength of the effluent inflow.

(2) Introduction of an autotuning facility. The selection and implementation of suitable auto-tuning software would facilitate the design of the gain scheduling controller.

6. References

[1] Fruehauf, P.S., Chien, I.-L. and Lauritsen, M.D. (1993). Simplified IMC-PID tuning rules, *ISA/93 Advances in Instrumentation and Control*, 1745-1766, McCormick Place, Chicago, Illinois, USA.

[2] Smith, O.J.M. (1957). Closer control of loops with dead time, *Chemical Engineering Progress*, **53**, 217-219.