Supervised Solutions for Precise Ratio Control: Applicability in Continuous Production Line

Ciprian LUPU, Dumitru POPESCU, Gabriel FLOREA

Faculty of Automatic Control and Computers,
Politehnica University of Bucharest,
Bucharest, Romania.
ciprian.lupu@acse.pub.ro, dumitru.popescu@acse.pub.ro, gabriel.florea@honeywell.com

Abstract: Applications of continuous production line technique is of vast use today when there is a high demand for mass production. One of the main disadvantages consists in high receptiveness to malfunctions since a single fault can stop or affect the quality of the entire production line. The paper presents an improved solution of (re)balancing a parallel control structure and maintaining the ratio between two adjustment quantities. Applicability is proved on a control structure of the ratio using two groups of tanks, a situation that has been encountered in the chemical industry, food industry, pharmaceutical industry etc. Meanwhile the proposed structure may represent an interesting solution that could be implemented within supervisory level.

Keywords: ratio control; control performance; control architectures; disturbance rejection, supervisory level.

1. Introduction

The high demand for mass production requires the implementation of the continuous (or flow) production line. The main advantages of the continuous production line are well-known: reduced processing time of work pieces; saving costs for temporary storage; control of the entire course of production (Figure 1). In the same time, one of the most important problems of the flow production is the high receptiveness to malfunctions since a fault can stop or affect the quality of the entire course of production. In many cases, from the food and pharmaceutical industry or from chemical dosing, water treatment, chlorination, mixing vessels [1] and waste incinerators, ratio or dosage loops are several of the important causes of quality problems and impose special solutions [6 -9], [16], [22].

In general terms, the ratio control between two or more process quantities was and continues to be an important subject in the area of practical applications. With time, various solutions, from

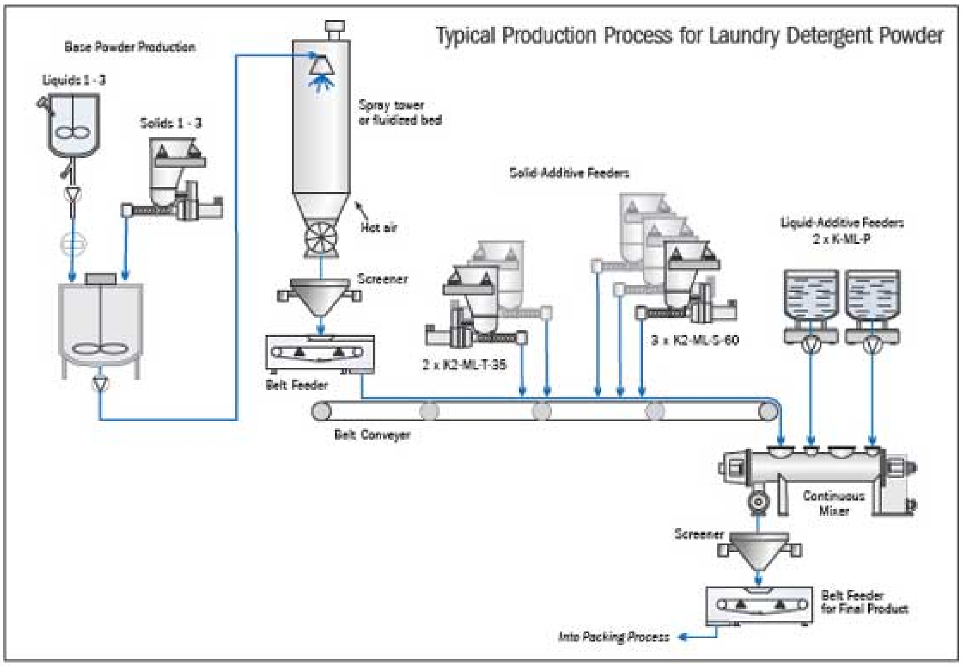


Figure 1. Example of continuous production line of the detergents [11]

simple ones as series or parallel (Figure 2) ordering of control loops to solutions using adaptive systems and structures, have been proposed and implemented. The purposes of these solutions are certainly those of increasing production performance and quality together with the efficient and safety exploitation of the production installation. A short list of works from this area can include [1-3], [5], [19-20].

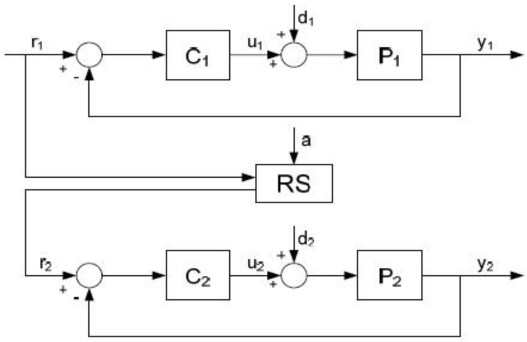


Figure 2. The typical ratio control scheme (parallel metered control) [1]

If the boundaries of the proper functioning of these systems are exceeded, the supervisory/safety level, present in most modern plants needs to be activated. Depending on the particularities of these systems, this intervention is focused generally on stopping the production line. Certainly, the (re) configuration of some elements of the production line could be a more convenient solution than stopping the entire process, but this operation is quite sensitive and generally requires additional hardware and software resources implementation, or sometimes flow production redesign [21], [23].

The paper tries to offer some performance solutions in which the ratio itself must be modified during the operation (in real time). The operation must be developed as fast as possible and with assuring the highest precision of keeping it in the transitory phase that follows the adjustment.

Even though this situation seems odd, it can be encountered when one of the recipients of a group product empties or is damaged and must be compensated with extra flows from similar recipients. Sometimes, using/adding parallel supply recipients represents the exclusive functional solution for the continuous production line.

In comparison to the classic solution and the one of the Visioli proposed variant [2] (Figure 3), the proposed solutions suppose variations of the modules balancing coefficient (from the included Blending Stations – BS_1 and BS_2). The notable results have been obtained in the situation where BS_1 and BS_2 are real time variables.

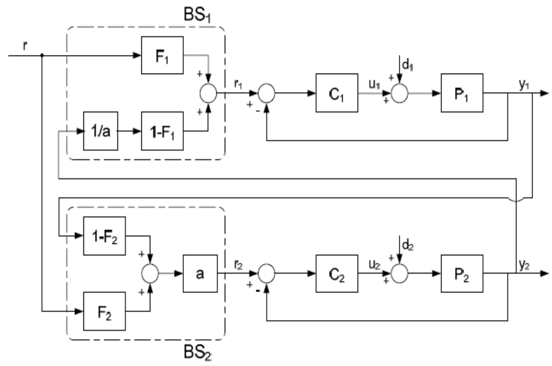


Figure 3. The proposed generalized ratio control structures involving two blending stations [2]

The testing scenarios have included perturbations to control loops, adjustments of setpoints values, adjustments of the value ratio (*a*) and compensations of the fail / emptiness of a reservoir, covering the main critical situations encountered in the real exploitation.

The comparative tests made are: a) a system with 4 reservoirs (2+2) equipped with (only) control loops on each reservoir vs. a system equipped with two extra fixed BSs; b) a system equipped with two extra fixed BSs vs. a system equipped with two extra adaptive BSs. Even though the (2+2) option is less favourable from the practical implementation viewpoint of the minimal construction, it was chosen because of the increased difficulty – losing a reservoir equalling a 50% (structural) perturbation.

The following sections will detail the above. The solution's applicability is demonstrated by means of real time simulations and laboratory experimental platform.

2. Proposed Control Structures

2.1 Industrial solutions

The parallel administration of identical systems seems to be rare but it can be encountered in various industrial situations or by analogy in the control traction of vehicles with independent engines / wheels / propellers. In this approach we will discuss the situation encountered in the chemistry / petro chemistry / pharmaceutical / food area.

Figure 4 (a) represents the situation in which for obtaining the final product, two “elementary components” A and B, obtained from two groups of reservoirs GA and GB, having (identical or different) NA, respectively NB components, are combined. The control loops of the flow are identical for the elements of groups A and B.

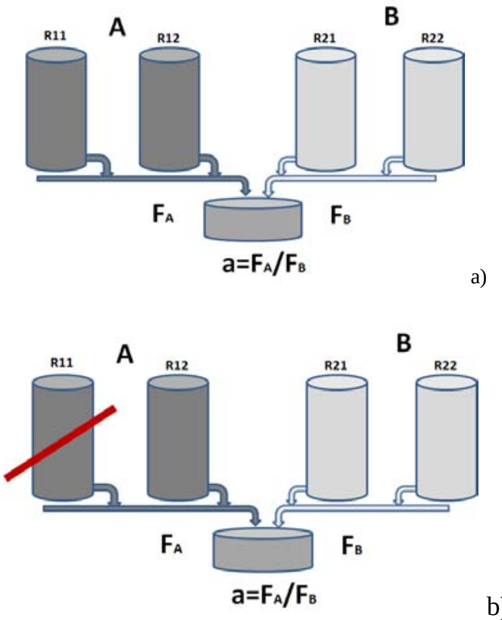


Figure 4. Installation with reservoirs (2+2)

The realized ratio (*aR*) is represented by (1) where *yA* and *yB* are total quantity/flow of products A and, respectively, B:

$$aR = \frac{yA}{yB} \tag{1}$$

The problem to which one is trying to find an answer is in the case that one of the reservoirs of group A or B gets faulty or empties as in Figure 4 (b). The normal solution is to increase the setpoint for the adjustment systems of the deficient group with a value depending on their numbers.

$$\Delta r = f(r, N_A, N_B) \tag{2}$$

In order to maintain in the most precise way of the *(a)* ratio, a solution would be using the generalized structure proposed by Visioli [1] and developed in [2]. The solution is noted by using a “mixing” block of the setpoints source – a blending station (BS). As presented in Figure 3, for each closed loop the setpoint is composed of the fraction of primary reference *r* added to the correspondent fraction of the parallel system exit *y1* or *y2*.

The functions F1 and F2 can be of dynamic (transfer function) or static nature - this means they can only have a simple value of static gain. For the “static” situation, the variation domain is [0 – 1]. Values close to 1 lead to a more direct dependence on the initial reference *r*. For the special case “equal to 1” the diagram is reduced to a parallel layout of the control loops (Figure 2). For values close to 0 the dependence setpoint on the parallel system exit is increased. In this case, a “solidarity” of the pursuance dynamic of the setpoints of the two systems is observed [7].

The applicative value of this control structure is very high because the extra elements involved are simple (gain blocks, adders) and can be easily found in real time software implementation libraries.

2.2 Proposed structure

In addition to the diagram in Figure 3, the proposed structure speculates on the NA and NB control loops instead of the singular control loop. The r1 and r2 setpoints are simultaneously applied to the NA and NB system groups.

The outputs of the parallels control systems from groups GA and GB are added in two sums. These are pondered by the corresponding parallel systems numbers NA and NB.

Figure 5 represents this structure. The normalizing blocks *1/NA* and *1/NB* implement formula (3) and have the purpose of maintaining the equivalency to the structure in Figure 3.

$$y_i = \frac{1}{N_i}\sum_{0}^{N_j} y_{ij}, \text{ where } i = A, B \tag{3}$$

In (3) for *j=2* the relationship is weighted to *a*.

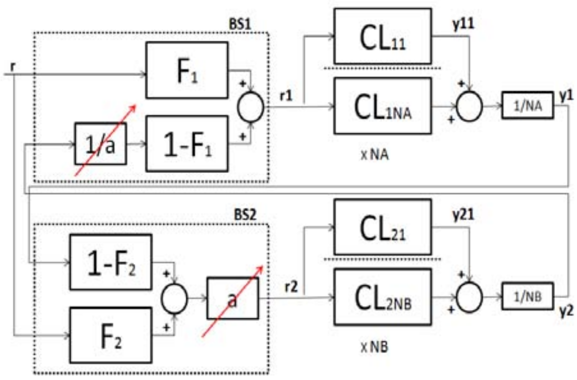


Figure 5. Proposed control structure

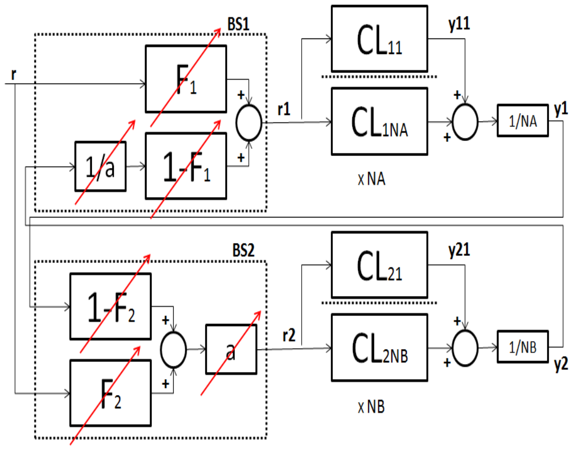


Figure 6. Proposed control structure variant

In this diagram the (a) ratio factor is variable, depending on the situation – reservoir / encountered defect.

The operation of the structure in case of intervention has as a two step strategy:

a) the general setpoint (r) change,

b) the (a) ratio change.

The combination of these steps must maintain the same output for the unaffected group and correct the affected recipient group situation.

The rules for changes, after simple calculus are presented in the next formulas. The general setpoint must be changed adding supplementary value as in:

$$r' = r + \Delta r \tag{4}$$

The setpoint variation is:

$$\Delta r = \begin{cases} r & , N = 2 \\ \dfrac{r}{N(N-1)}, & N \geq 3 \end{cases} \tag{5}$$

Here, there can be seen that maximal variation is obtained for the N=2 situation where the new setpoint is doubled.

The new (a') ratio control is

$$a' = \begin{cases} \dfrac{a}{2} & , N = 2 \\ \dfrac{a}{1 + \dfrac{1}{N(N-1)}}, & N \geq 3 \end{cases} \tag{6}$$

or, the equivalent:

$$a' = \begin{cases} a\dfrac{1}{2} & , N = 2 \\ a\dfrac{N(N-1)}{1 + N(N-1)}, & N \geq 3 \end{cases} \tag{7}$$

As an example in Figure 4 - the case of (2+2) recipients:

$$r'_A = r_A + \Delta r'_A \tag{8}$$

$$N = 2 \Rightarrow r'_A = 2r_A, a' = \frac{a}{2} \tag{9}$$

2.3 Variants of the proposed structure

The structure can provide an additional degree of adaptation about F1 and F2 variables, so that, according to the situation – the normal way of functioning – that of compensating for defective reservoirs, they can be adapted to the idea of a more correct evolution of the structure. As there will be presented in the experimental tests, in major disturbances situation F1 and F2 are decreased to 0.1.

The control algorithms can be PI, PID [14], [15], [17], RST etc. It is recommended to ensure different performance in the set point tracking and disturbance rejection, as RST [4].

The applicability of these structures is proven in the following experimental tests.

2.4 Supervisory level integration

In most powerful SCADA or DCS software developing tools there are special blocks for ratio control [24], [25], as presented in Figure 7.

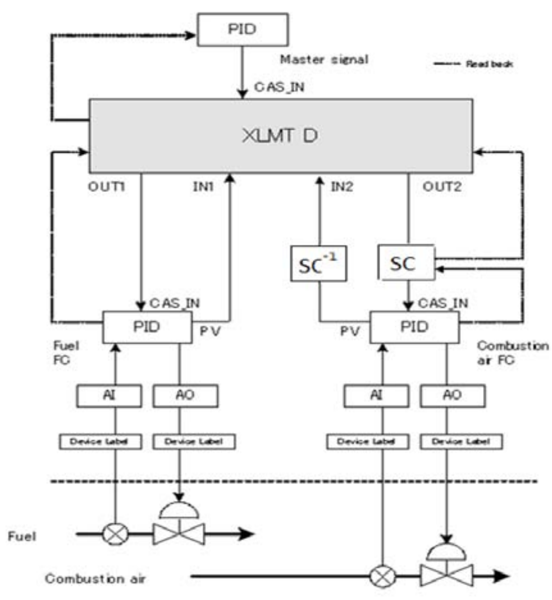


Figure 7. Yokogawa FBD block for ratio control

Here, for example, the "XLMT D" block drives two control loops (PID) for combustion ratio. These structures provide superior performance compared to the use of simple parallel or series of control loops, but there are still enough places for optimization.

In general, software tools for DCS and safety levels application are different; the hardware is in turn different. Depending on the plant particularities and the available hardware architectures there can be identified at least two situations:

– the control level includes only (control) loops and the remaining calculation elements (Figure 5) included in supervisory/safety level;
– all the elements included in the control level and just the ratio supervision included on supervisory/safety level.

Both situations involve advantages and disadvantages; for example first option only requires the transfer of setpoints between the levels of supervision and control, but requires the implementation of all calculations in the supervisory application, as presented in Figure 8.

The second option, on the contrary, requires full implementation in the control level of the proposed structure. The choice depends on the facility and the restrictions imposed on development tools and plants.

3. Simulations and Experimental Tests

For validating the proposed system performance several diagrams have been implemented in Matlab - Simulink and various evolution scenarios have been imagined.

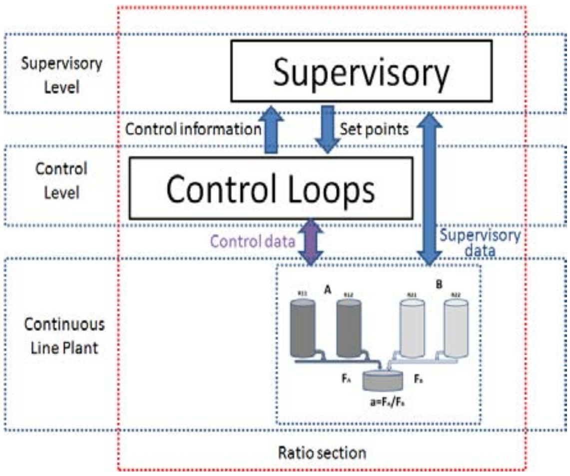


Figure 8. Ratio control and supervisory section of flow production line

The comparative developed tests are:

a) a system with 4 reservoirs (2+2) equipped with (only) control loops on each reservoir (Figure 9 with NA, NB = 2) vs. a system equipped with two extra fixed BSs ;
b) a system equipped with two extra fixed BSs vs. a system equipped with two extra adaptive BSs.

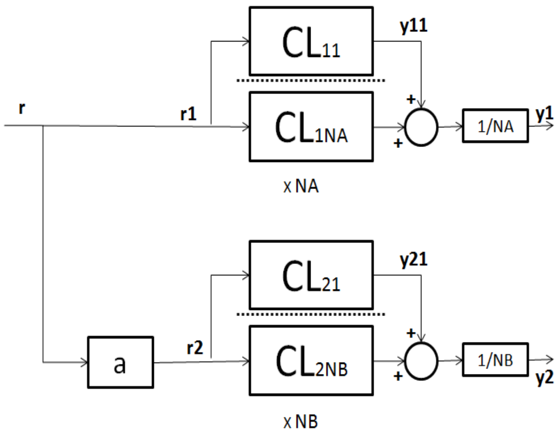


Figure 9. A System with NA and NB parallel reservoirs equipped with (only) control loops

In the next tests the quality criteria are the signed ratio error integral evolution and the absolute (modulo) ratio error integral evolution, based on the desired ratio (*a*) and realized ratio (aR) presented in (1):

$$aERR_i = a - aR_i \tag{10}$$

$$aERRs = \frac{1}{N_s}\sum_{0}^{Ns} aERR_i \tag{11}$$

$$aERRa = \frac{1}{Ns}\sum_{0}^{Ns} \left|aERR_i\right| \tag{12}$$

where i=0 – Ns; Ns is number of samples.

The initial ratio – *a* - is considered equal to 2 and the setpoint is set to 1. After the systems stabilization, it is considered that reservoir R11 fail (sample 70 in next figures). As balancing strategy, calculated in (9), the *a* ratio is reset to 1 and the setpoint value increased to 2.

The combination of these two measures (imposed at the same 70 sample moment) determines the group B output to remain at the same value - 2. In the same time, group A output increases to 2 (from the remaining R12 reservoir, the output is doubled).

3.1 Test a) - a system with 4 reservoirs (2+2) equipped with (only) control loops on each reservoir vs. a system equipped with two extra fixed BSs

For this test, F1 and F2 are the constant gains, close to 1. In the following figures the used colours are: group A / 1 – yellow, group B / 2 – blue, *a* ratio error – magenta. In general lines, in Figure 10 there can be seen that the two structures have similar evolutions: on the setpoint tracking evolution and on successfully solving the reject reservoir R11 fail - disturbance. But, by representing the signed ratio error integral evolution (Figure 11) there can be seen that the second system provides superior performance – lower error value (down). The same good results for the proposed structure are obtained for the absolute (modulo) ratio error integral evolution (Figure 12).

These results sustain the proposed structures, derived from the generalized Visioli's structure [1], [2].

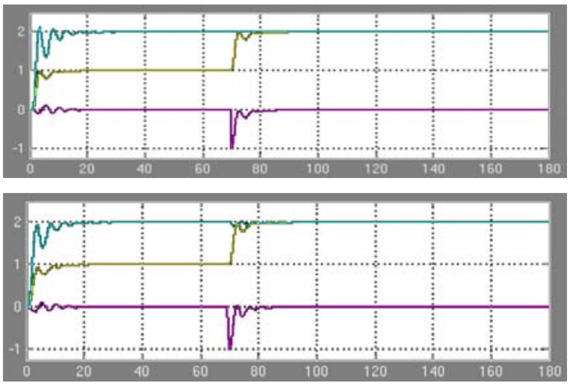


Figure 10. A system with 4 reservoirs (2+2) equipped with (only) control loops (up) vs. a system equipped with two extra fixed BSs (down)

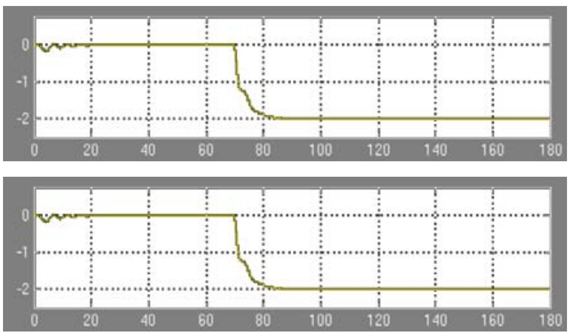


Figure 11. Signed ratio error integral evolution - A system with 4 reservoirs (2+2) equipped with (only) control loops (up) vs. a system equipped with two extra fixed BSs (down)

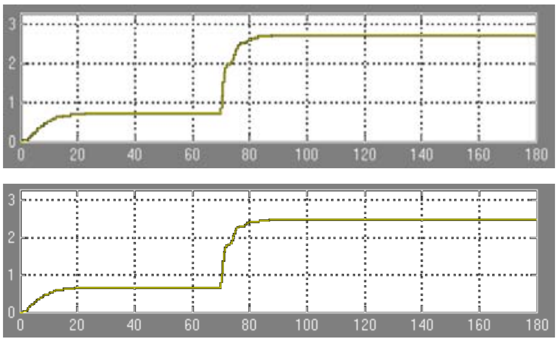


Figure 12. Absolut ratio error integral evolution – A System with 4 reservoirs (2+2) equipped with (only) control loops (up) vs. a system equipped with two extra fixed BSs (down)

3.2 Test b) - a system equipped with two extra fixed BSs vs. a system equipped with two extra adaptive BSs

For this test, F1 and F2 are the variable gains, initially close to 1 and finally close to 0.1 (after R11 fails).

In Figure 13 there can be seen that the two structures have similar evolutions about tracking the setpoint evolution and different about the reject reservoir R11 fail - disturbance. For the adaptive solution, the decreasing of F1 and F2 to a small value (0.1) gave a specific evolution – dynamic solidarity. So, both evolutions are almost superposed.

The signed ratio error integral evolution (Figure 14) shows that the second system provides important performance – lower error value (down figure). But, the results are opposite for the absolute (modulo) ratio error integral evolution (Figure 15). Here, there can be seen that the non adaptive structure ensures microscopic advantages.

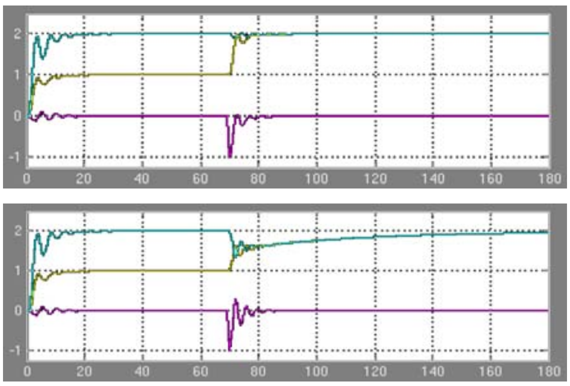


Figure 13. A System equipped with two extra fixed BSs (up) vs. a system equipped with two extra adaptive BSs (down)

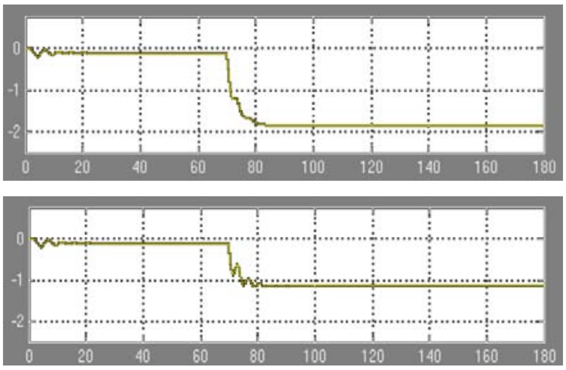


Figure 14. Signed ratio error integral evolution – A System equipped with two extra fixed BSs (up) vs. a system equipped with extra adaptive BSs (down)

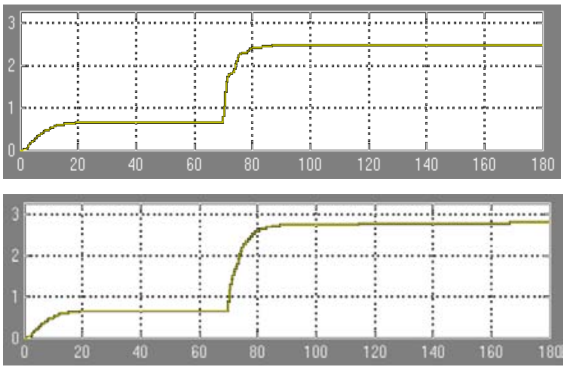


Figure 15. Absolut ratio error integral evolution – A System equipped with two extra fixed BSs (up) vs. a system equipped with extra adaptive BSs (down)

In conclusion, the adaptive option is recommended for systems that allow the mixing of products A and B in an intermediate buffer tank, as represented in Figure 4.

3.3 Real time tests

To complete the Matlab – Simulink, functional experiments were performed during several laboratory tests on a small scale industrial plant. Its purpose was to control the flow of four fluids from four separate reservoirs, similar to the Figure 4 situation.

It was first implemented a control – supervisory structure; here, the control level includes only control loops and the remaining calculation elements are implemented on the supervisory level (Figure 8). Figure 21 presents real time (C code) supervisory implementation sample.

The plant structure was designed based on four Festo Compact Workstations [13] (Figure 16. – a – left side). Here, the main elements are four electric pumps and four flow sensors. The connection between the process platform and the computer was made using four National Instruments NI USB 6008 [12] data acquisition devices (Figure 16. - b - right side). This application is launched four times (a, b, c, d) for each flow process.

a) b)

Figure 16. Experimental laboratory platform – Festo Compact Workstations and National Instruments NI USB 6008 data acquisition devices

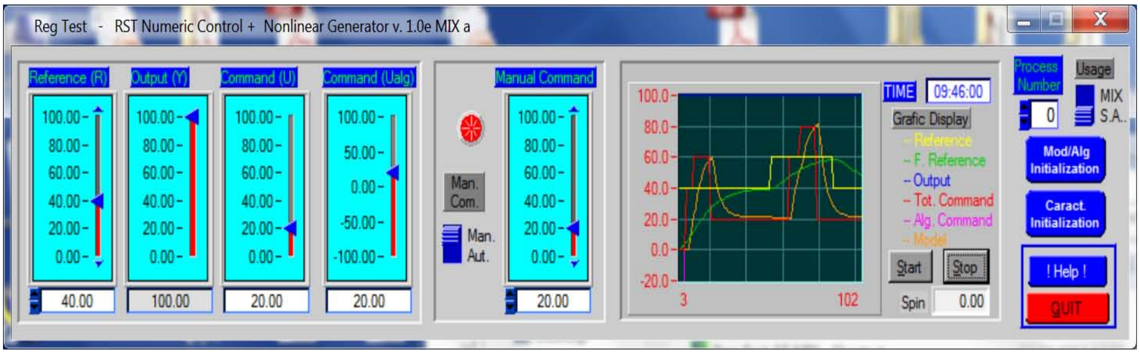
Two real time software applications for control were developed in the National Instruments - LabWindowsCVI package [12]. The first one, Figure 17a - (Reg_Test_NL_10e_MIX_6008a, b, c, d) implements a single closed loop control with RST [4] algorithms and nonlinearity compensation (if necessary). The second one – Figure 17b, (Reg_Test_37_MIX) implements the proposed ratio control structure presented in Figure 5 and sends setpoints values for the four closed loops – the first application. Using these software applications there are made a few tests such as setpoint chance, reservoir removing – fail, reservoir adding etc., as presented in the following paragraphs.

In all the experiments presented in the next figures, the left side represents the setpoint evolution - with red colour Group A / 1 (R11 and R12) and with blue Group B / 2 (R21 and R22), and the right side - ratio error. The Festo flow sensors which were used allow 0.3 – 9.0 l/min measuring range, corresponding to 0% to 100%, so during the experiments the setpoint was modified between 2 – 7 l/min.

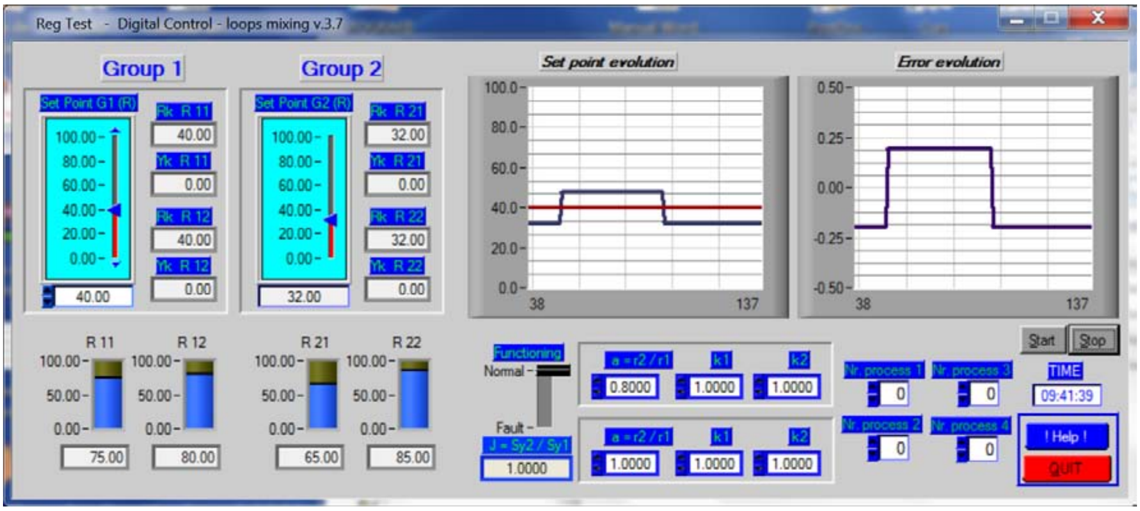
```
// BS1 Block (see Visioli et al.  [2])                // BS2 Block (Visioli et al. [2])

rkg1=f1*rbk+(1/A)*(1-f1)*ykg2;               rkg2=A*(f2*rbk+(1-f2)*ykg1);
```

Figure 21. Supervisor implementation in ANSI C



a)



b)

Figure 17. (a) single closed loop RST controller; (b) proposed control structure (variant solution)

Figure 18 represents a normal setpoint change from 65% to 50%. There can be seen that the mixing structure “protects” the ratio control evolution and after the transitory evolution this parameter error tends to 0.

In figure 19 there are presented the fault situation evolutions: the brutal setpoint change after the R11 removing, and the ratio error recovery.

The Group B / 2 setpoint is modified to help according to the ratio error decrease. The

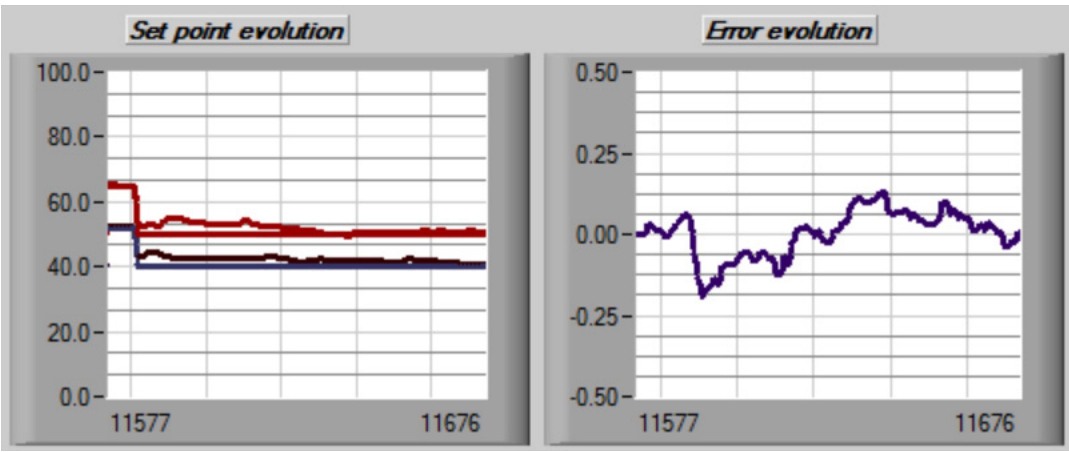


Figure 18. Real time evolution – setpoint change (left), ratio factor error (right)

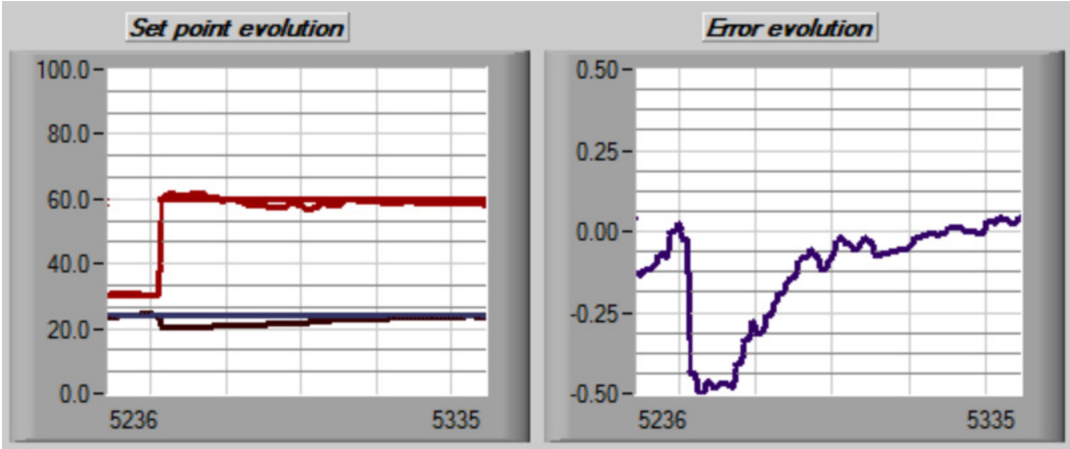


Figure 19. Real time evolution – fault rejection: setpoint change (left), ratio factor error (right)

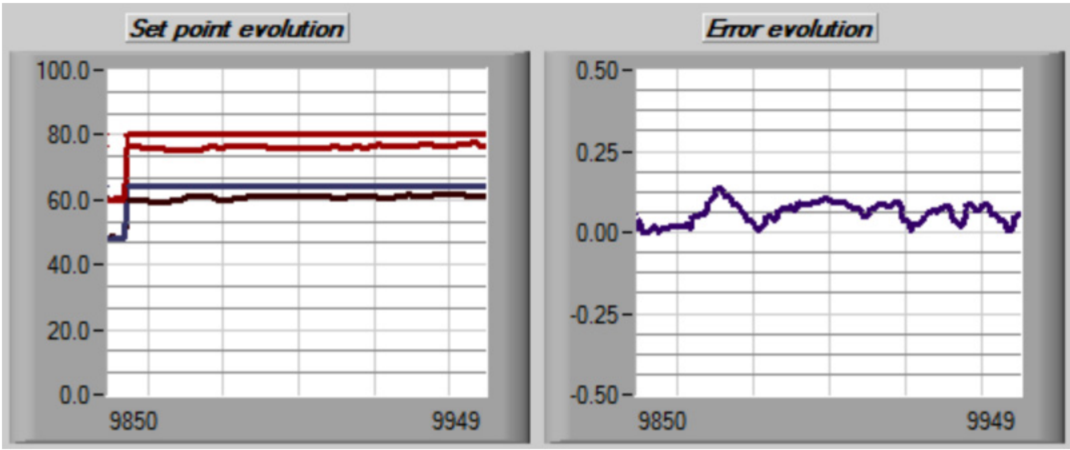


Figure 20. Real time evolution – setpoint change and physical system limitation: setpoint change (left), ratio factor error (right)

evolutions are similar to the simulation case (Figure 14 up).

Figure 20, presents the same, a setpoint change evolution but, after the setpoint change, it is possible that this new functional point couldn't be reached, because one or more of the reservoirs do not have enough substance.

So the mixing structure imposes a corresponding setpoint to the parallel group, so as ratio could be maintained. In this case, on real exploitation, some specific Safety System must alarm human operators about it.

4. Conclusions

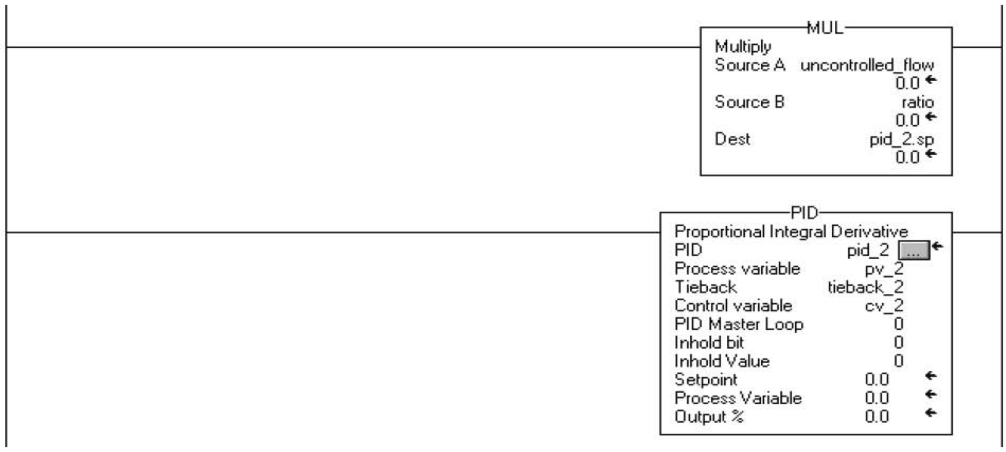
As a general conclusion the proposed structures ensure superior performance versus the simple multiple parallel controls (Figure 9). In this paper there are considered as already demonstrated closed loops disturbances rejection performance presented in [1], [2], [6] and [7].

In structural disturbances as reservoir fail, the value which modifies the ratio factor is 1/N, where N is the number of reservoirs of the same side. If N is bigger the bump is smaller and the precision better.

In industrial exploitation there are identified two distinct cases: the first one, where products A and B are used directly, without mixing; and second one, where A and B are intermediary mixed in an auxiliary tank. For the second situation the integration of the signed value of ratio error is the most adequate criterion and for the first one, the integration of the absolute (modulo) value of ratio error criterion is better.

In the a) tests using an adaptive ratio – a - for structural disturbances cases, as reservoir fail, provides an improvement of the ratio error of about 7-10% on both criteria.

Relay Ladder



Structured Text

```
pid_2.sp := uncontrolled_flow * ratio

PID(pid_2,pv_2,tieback_2,cv_2,0,0,0);
```

Figure 22. Ratio implementation on Rockwell Logix5000 in Leader and Structured text languages [25]

In the b) tests using an adaptive ratio – *a* - and parameters F1, F2 for structural disturbances, provide an improvement of the ratio error only for the signed error criteria. This fact recommends it for the supplementary mixing reservoirs (as in Figure 4).

In all the Simulink tests simple PI control algorithms were used; one of the used test program is presented in Figure 23. For superior performance there are recommended two degrees of freedom algorithms, as RST [4].

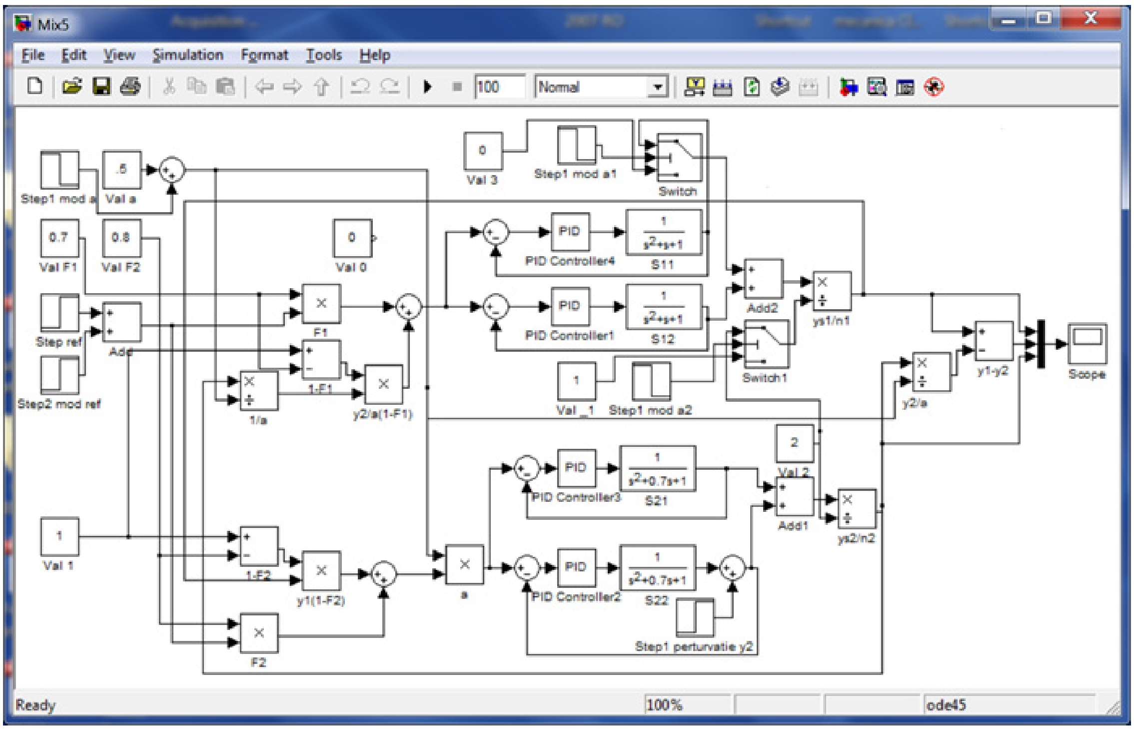


Figure 23. Implemented Matlab-Simulink simulated structure

Real time tests made on reduced scale industrial processes confirm the simulation tests evolution and complete the conclusions with some interesting results.

So, during laboratory tests there was identified a special situation, when wanting to turn off the system by imposing a general setpoint (*r)* to a null value, one of the flows did not stop completely (a situation which is impossible in simulation). The implemented mixing system kept the appropriate reference flow parallel group so that the errors report to be as close to 0. As a result, the global system does not stop. This observation could be included in the corresponding standard exploitation (ISO etc.) to be solved on the Safety hierarchical level.

The proposed structures will be implemented experimentally on a real process in the petrochemical industry.

Acknowledgment

This work was cofinanced by University Politehnica of Bucharest - A.C.P.C. Research Center projects from the Automatic Control and Computer Faculty.

Nomenclature

C1 / C2 is the controller number 1 / 2

P1 / P2 is the process number 1 / 2

r1 / r2 is the setpoint for loop 1 / loop 2

r is the general/primary setpoint

a / aR is the ratio (imposed) / realized ratio

y1 / y2 is the output from process/loop 1 / 2

u1/ u2 is the output from controller 1 / 2

d1 / d2 is the disturbance that affect process 1 / 2

BS1 / BS2 is the blending station 1 / 2

F1 / F2 is the function included in BS1 / BS2

yA / yB is the total quantity of products A / B

GA or A is the group of products A or number 1

GB or B is the group of products B or number 2

NA / NB is the number of elements in group A or GA / B or GB

$aERR_i$ is the ratio error on instant i

$aERRs$ / $aERRa$ is the signed / absolute ratio error integral evolution

Ns is the total number of samples

REFERENCES

1. VISIOLI, A., **Practical PID Control**, Springer, London, 2006.
2. ENGIN, Y., G. MUJDE, E. IBRAHIM, **A Ratio Control Structure with Two Blend Stations**, The 5th IFAC International WS DECOM-TT, May 17-20, Cesme, Turkey, 2007, pp. 111-116.
3. HÄGGLUND, T., **The Blend Station – A New Ratio Control Structure**. Control Engineering Practice, vol. 9(11), 2001, pp. 1215-1220.
4. LANDAU, I. D., R. LOZANO, M. M'SAAD, **Adaptive Control**, Springer Verlag, London, 1997.
5. SELL, N. J., **Process Control Fundamentals for the Pulp & Paper Industry**, Cap. 10, Tappi Press, ISBN: 0898522943, 1995.
6. DAI, X., D. HE, T. ZHANG, K. ZHANG, **Generalized Inversion for the Linearization and Decoupling Control of Nonlinear Systems**, IEEE Proc. Control Theory Application, 2003, pp. 267-277.
7. LUPU, C., D. POPESCU, R. GYORODI, A. UDREA, **Precise Ratio Control Structure for Nonlinear Blend Processes**, 20th MED Conference, Barcelona, July 3-6, 2012, pp. 1328-1333.
8. WU, J., et al., **A Novel Failure Mode Analysis Model for Gathering System based on Multilevel Flow Modeling and HAZOP**. Process Safety and Environmental Protection, vol. 91(1-2), 2013, pp. 54-60.
9. SOMNATH, R., A. SUMANTA, **Scalar Mixing in a Turbulent Stirred Tank with Pitched Blade Turbine: Role of Impeller Speed Perturbation**, Chemical Engineering Research and Design, vol. 90(7), 2012, pp. 884-898.
10. POPESCU, D., D. STEFANOIU, C. LUPU, C. PETRESCU, B. CIUBOTARU, C. DIMON, **Industrial Automation**, Editura AGIR, Bucuresti, 2006,
11. *** retrived from http://www.ktron.com/industries_served/chemical/laundry_detergent_production.cfm

12. *** National Instruments, NI USB 6008, retrived from, http://www.ni.com

13. *** Festo A.G., retrived from http://www.festo-didactic.com

14. MCDONOUGH, R. J., **Mixing for the Process Industries**, Van Nostrand Reinhold, New York, 1992.

15. NAUMAN, E. B., **Chemical Reactor Design Optimization and Scale-up**, McGraw-Hill, New York, 2002.

16. PATEL, D., F. EIN-MOZAFFARI, M. MEHRVAR, **Dynamic Performance of the Continuous-flow Mixing of Pseudoplastic Fluids Possessing Yield Stress in Stirred Reactors**, Industrial & Engineering Chemical Research, vol. 50(15), 2011, pp. 9377-9389.

17. VISIOLI, A. Q.-C. ZHONG, , **Control of Integral Processes with Dead Time**, Advances in Industrial Control, Springer-Verlag London Limited, 2011.

18. LUPU, C., A. UDREA, AL. TICLEA, **Control Solution for Some Classes of Nonlinear Processes**, 19th IEEE MED Conference, Corfu, 2012, pp. 1046-1051.

19. DONG, Y. L., et al., **The Flow Ratio Process Control System Design Based on Improved PID Algorithm**, Advanced Materials Research, 2012, pp. 605-607.

20. LUPU, C., C. PETRESCU, **Balancing Strategy for Ratio Control Structures**, 19th CSCS Conference, Bucharest, 2013, pp. 430-434.

21. BRUSAFERRI, A., A. BALLARINO, E. CARPANZANO, **Reconfigurable Knowledge-based Control Solutions for Responsive Manufacturing Systems**, Studies in Informatics and Control, vol. 20(1), 2011, pp. 31-42.

22. FILIP, F. G., A. D. DONCIULESCU, G. NEAGU, **Decision Support for Blend Monitoring in Process Industries**, Computers in Industry, vol. 36(1-2), 1998, pp. 13-19.

23. HERNANDEZ-MARTINEZ, E. G., et al., **Modeling Framework for Automated Manufacturing Systems Based on Petri Nets and ISA Standards**, Studies in Informatics and Control, vol. 22(2), 2013, pp. 163-174.

24. *** Yokogawa Electric Co., Retrived from http://www.yokogawa.com/iss/documents/iss-doc-download-e.htm

25. *** Allen-Breadley, Rockwell Automation, **Logix5000 Controllers General Instractions – Reference manual**, Publication 1756-RM003I-EN-P, January, 2007.