Non-Obtrusive Stiction Detection Methods for Control Systems

Article *in* Technology Reports of Kansai University · August 2020

ISSN: 04532198
Volume 62, Issue 07, August 2020

Non-Obtrusive Stiction Detection Methods for Control Systems

Leonardo Escobar Davidson[1], Stephany Sucerquia Rincones[1], Samir Hadechni Bonett[1], Jhon Ramirez Parra[1], Jean Coll Velasquez[1], Kelvin Beleño Saenz[1], Javier Jiménez-Cabas[2], Carlos Díaz Saenz[1]

Universidad Autónoma del Caribe, GIIM research group, Barranquilla, Colombia[1]
Departamento de Ciencias de la Computación y Electrónica, Universidad de la Costa, Barranquilla, Colombia[2]

Abstract— Industrial processes play a key role in the production sector. Production demands have forced the search for strategies such as automatic diagnosis to maintain continuous production with minimized machine failures. An industrial process provides many measured, controlled, and manipulated variables that associate nonlinearities and uncertainties, so it is necessary to monitor them, to acquire information about the behavior of the process. Historical and present information resulting from monitoring is used to implement intelligent monitoring systems. Within the monitoring scheme is the detection of failures, diagnosis, and restoration of operating conditions according to process performance criteria [1].

Keywords— Control systems, Hysteresis, Cross correlation, Non-linearity, Curve fitting.

1. Introduction

The diagnostic procedure begins when oscillation is detected in the control loop, the most common origin of this variation occurs in the actuators, mainly in the control valves because these are exposed to both external and internal factors during the process, as friction in the valve increases, it moves more slowly, which in some cases causes it to jam momentarily and suddenly jump to another position, causing unwanted process oscillations, in order to detect these oscillations is made use of a number of non-invasive detection methods. With this computational tool you can analyze and diagnose the possible static friction failures that can occur in the control elements (actuators) and the parameters to be considered according to the type of process [2].

2. Tools and Methods

2.1 Mathematic Models

Three methods were integrated through the MATLAB® application plus the toolbox AppDessigner, in which they were implemented and developed. The first method called 'nonlinearity detection and PV-OP pattern analysis' is based on the analysis of the graph obtained by overlapping the mv data against the OP data so no mathematical model was necessary. The second method called 'cross-correlation-based stiction detection' requires a mathematical model which is, cross correlation function observed in Equation 1.

$$(f * g)_i \stackrel{\text{def}}{=} \sum_j f^{*}_{j} g_i + j \qquad (1)$$

This function was used to obtain a graph that corresponds to the similarity between two signals, in this case, of the OP and PV data, during the development of the computational tool in the MATLAB® software, the function 'xcorr' whose syntaxis is: r xcorr(x,y) was used; where 'x' and 'y' are the PV and OP data.

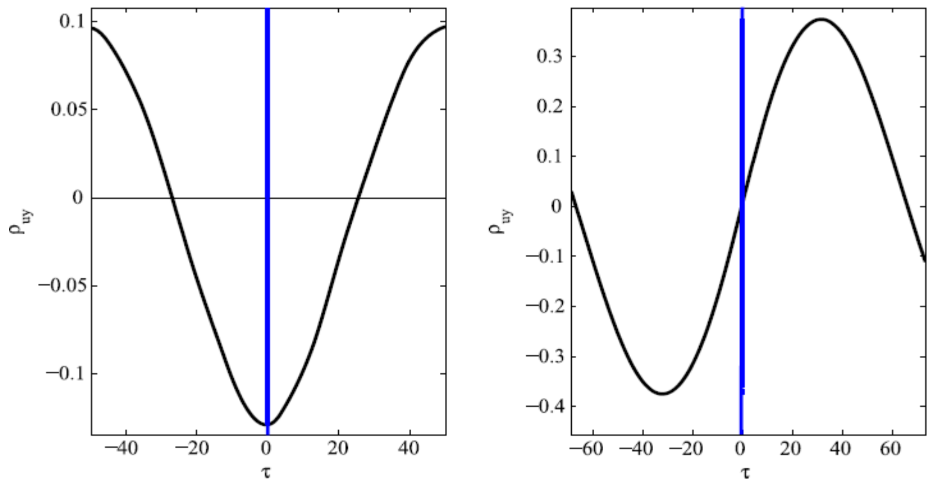

Figure 1. Cross-correlation between control signal and process output for the case of no stiction (left) and stiction (right).

For the third method, called 'diagnosis based on curve adjustment' was used a numerical iterative method, i.e. Nonlinear least-square method was used to find the best fitting for the sine curve, and a polynomial adjustment was used for the triangular curve [10].

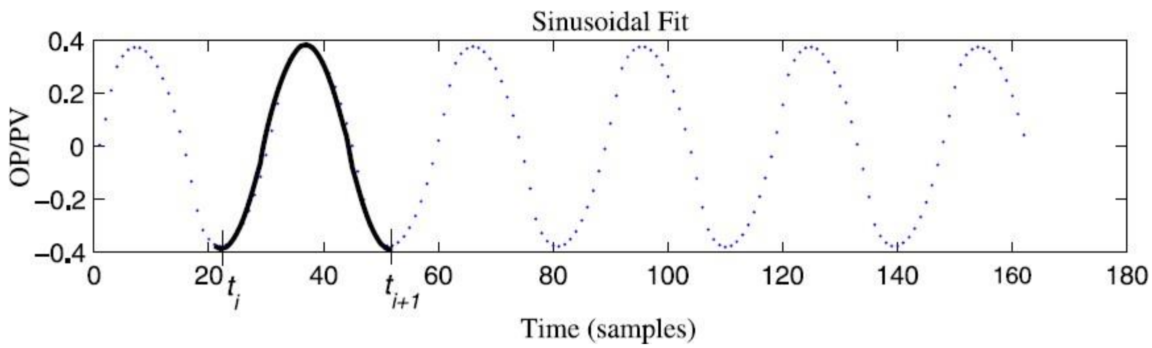

Figure 2. Sine adjustment.

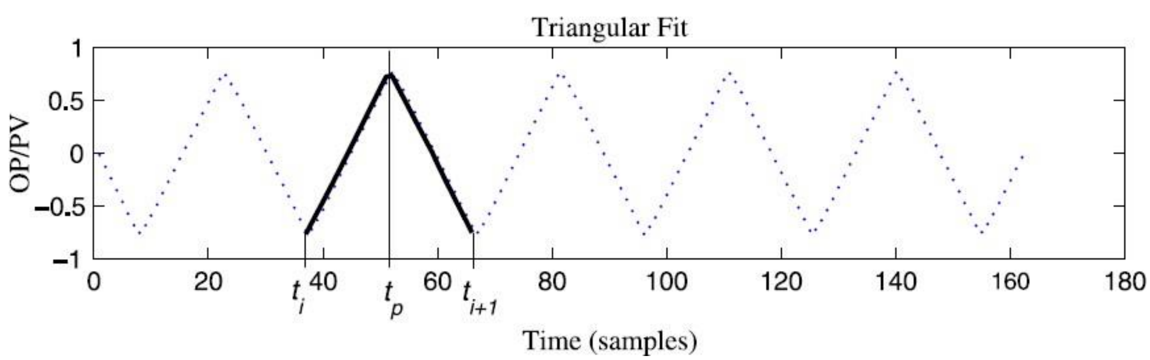

Figure 3. Triangular fit.

In MATLAB software®, the 'polyfit' function was used for the triangular setting, and the 'lsqcurvefit' function was used for the sine setting.

2.2 Boundary Conditions

The computational tool developed in the MATLAB AppDesigner toolbox [4], is divided into tabs, the first

ISSN: 04532198
Volume 62, Issue 07, August 2020

shows an overview of the system to be analyzed (**Figure 4**), on the other 3 tabs apply the methods mentioned above.

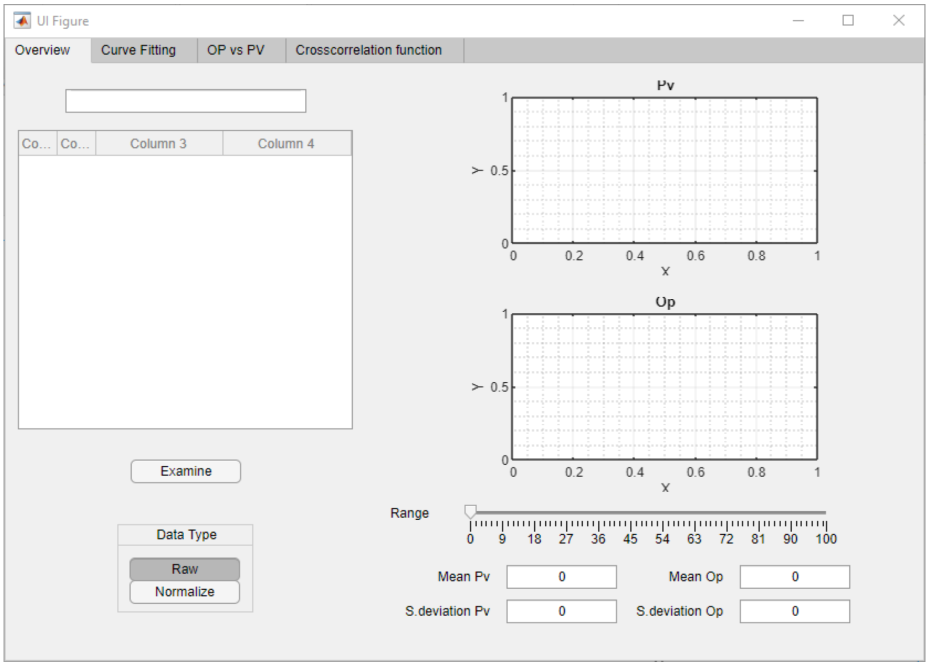

Figure 4. Overview computational tool.

The data is inserted in the format (.xlsx), with the parameters; time, set point, process variable, and output consecutively on each column in the table.

2.3 Design

In this window (**Figure 5**), you can see all the data with which the tool works in addition to being able to see the graphs of the PV and OP data, at the bottom there is a slider bar to manipulate the maximum range of the horizontal axis of both graphs, and finally the values of the mean and the standard deviation of both variables and the possibility to display the normalized or in-filter graphs.

Figure 5. Overview of data loaded.

In this tab (**Figure 6**), the curve fitting method is applied, which consists of taking the PV and OP data and adjusting it to a sine and triangular wave, respectively. One of the common characteristics of the controlled variable and the manipulated variable is the pattern of its curve, so for this method it is performed a fitting of PV, to detect the typical signature of stiction and distinguish it from other causes, to both sinusoidal (**Figure 2**) and triangular (**Figure 3**) uses a segment of the curve equal to 10% of its total size [12] [11]. If the fit for the triangular wave is better, then stiction is concluded, otherwise no stiction occurs. By comparing the error between real and fitted data, an evaluation of the accuracy of approximation and then a stiction index can be obtained [6].

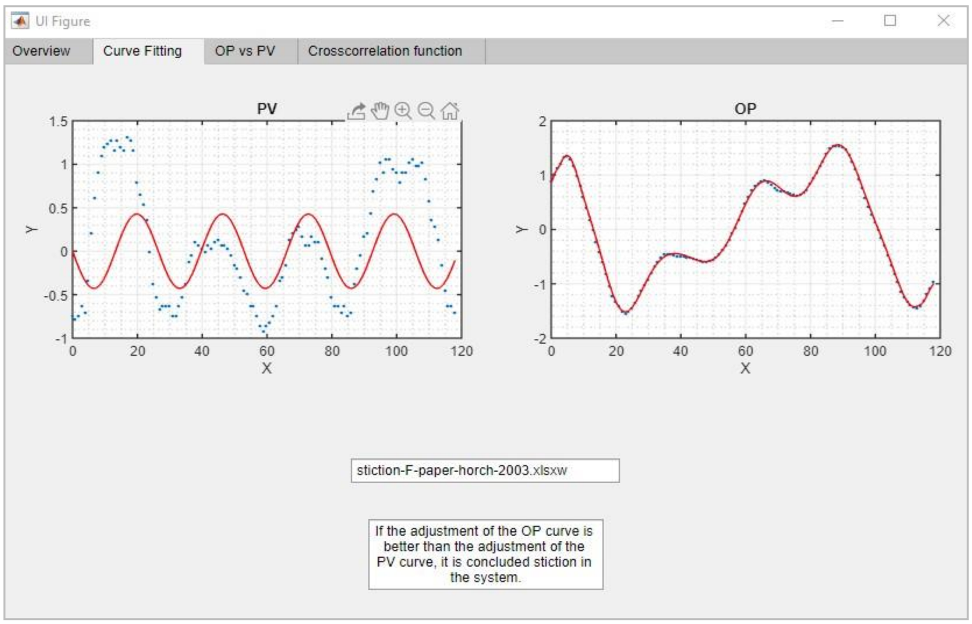

Figure 6. Curve fitting.

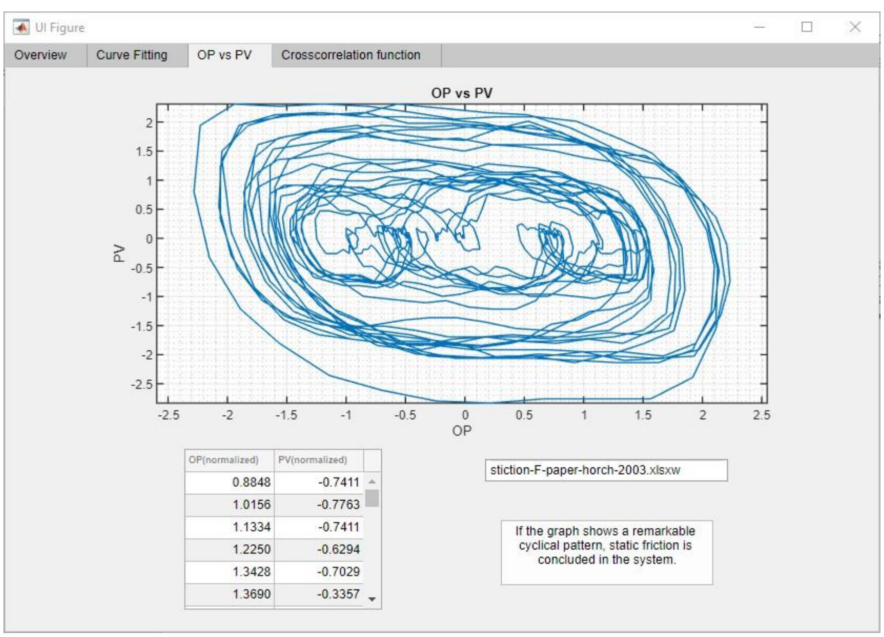

Figure 7. OP vs PV.

In this tab (Figure 7), the 'Nonlinearity detection and PV-OP pattern analysis' method is applied, in which the PV variable data is plotted against the data of the OP variable. In this method the detection of valve or process nonlinearity is first carried out using higher-order statistical method-based. Once a nonlinearity is detected, the data are treated by a wiener filter, and the PV–OP plot, generated from a segment of the data that has regular oscillations, is used to its cause isolate. A signature of valve stiction is when PV–OP plot shows cyclic or elliptic patterns. If not, such patterns are observed, it is concluded that there are valve problems, but these are not due to the stiction [8].

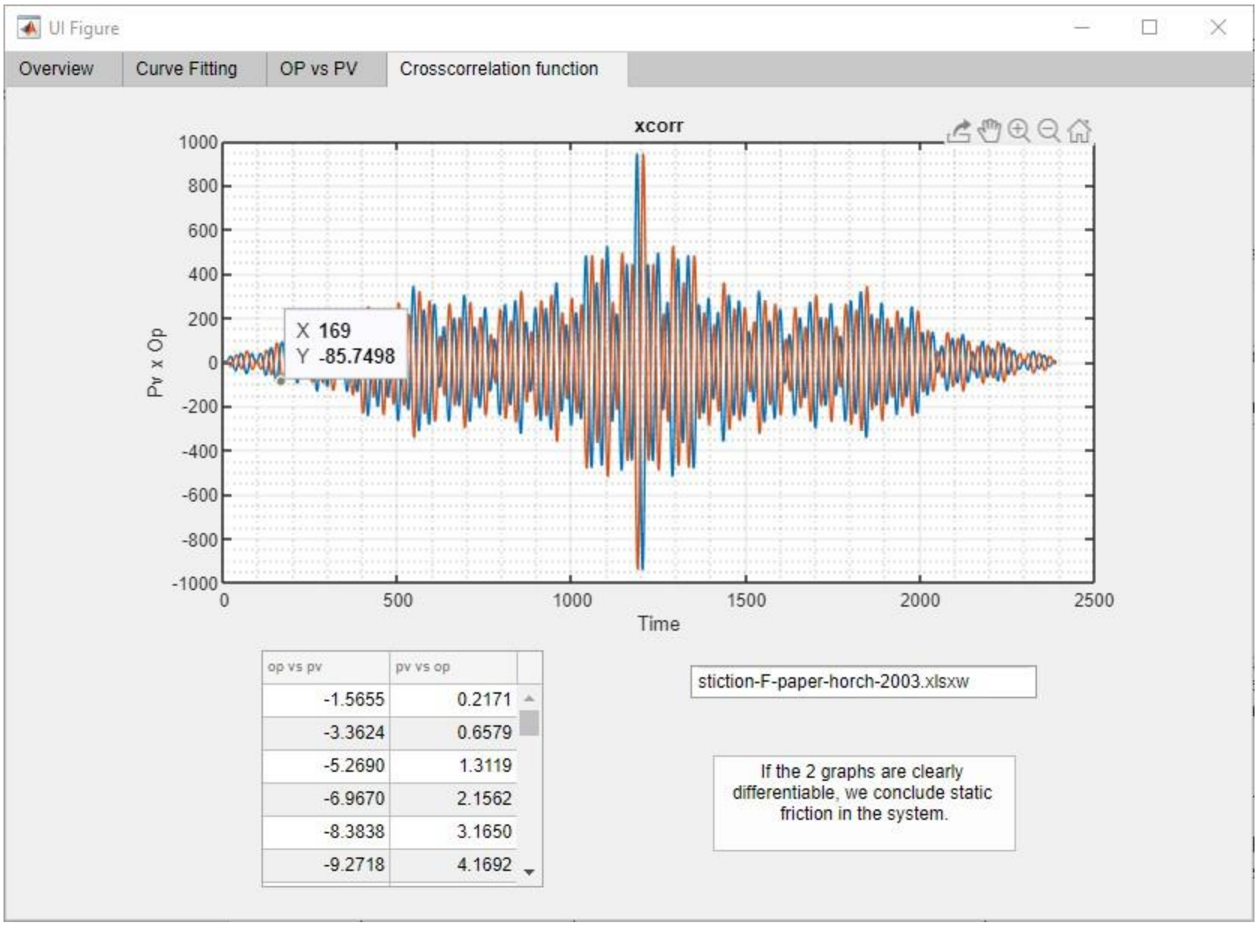

Figure 8. Cross-correlation function.

In this tab (figure 8), the 'Static friction detection based on cross-correlation' method consisting of the analysis of the cross-correlation plot between the OP variable and the PV variable is applied. This was the simplest method to implement because it is based entirely on the analysis of the cross-correlation function.

If the cross-correlation function between controller output OP and process variable PV is an odd function (i.e. Asymmetric with the vertical axis), the likely cause of the oscillation is stiction.
• if the cross-correlation function graph is even (i.e. Symmetric with the vertical Axis), then stiction is not likely to have caused the oscillation. In this case, the oscillation may be due to external disturbances, interaction, or aggressive tuning of the controller. [3]

The following assumptions are needed to apply this stiction detection method:
• the process does not have an integral action.
• the process is controlled by a pi controller.
• the oscillating loop has been detected as being oscillatory with a significantly large amplitude.

3. Results and discussion

A comparative table (**Table 1**) was made to determine the three methods to be implemented according to the established requirements, being selected: Cross-Correlation-based stiction detection, nonlinearity detection and PV–OP pattern analysis, diagnosis based on curve fitting. Those that met the objective of detecting static friction in control loops.

Table 1. Comparative table.

Static friction detection based on cross-correlation	Simple statistics and advanced diagnostics. Great pressure handling and reliability [9].	Diagnoses static friction by nonlinearity and displacement in actuators.
Nonlinearity detection and PV-OP pattern analysis	It is performed first using a higher order statistical method based on ngi and nli indexes, once it is detected or not linearity, the data are processed by a wiener filter (pvf, opf) and the pvf – opf chart, generated from a segment of the data that has regular oscillations, are used to isolate its cause [5].	Diagnoses nonlinearity, analyzing valve movement behavior or changing the input signal to the valve.
Diagnosis based on curve adjustment	A SP-OP, or SP-PV data adjustment is performed to detect the typical static friction signature and distinguish it from other causes [7].	The output controller or process variable conforms in parts (each significant half cycle) to the triangular and sinusoidal curve segments using a ls method

Therefore, the tool that was presented allows to show the results of the detection of oscillations from the application these methods. The 'cross-correlation-based stiction detection' method detects static friction by analyzing the cross- correlation function applied to the PV and OP variables, on the other hand, the 'nonlinearity detection and PV–OP pattern analysis' method detects disturbances from analysis and similarity with cyclic or elliptical patterns, and finally the 'diagnosis based on curve fitting' method that allows static friction to be detected by adjusting the data to ideal curves with the same properties(period, etc.). Tests were carried out with different databases found in the sacac repository to verify the optimal functioning of the computational tool in situations where the process presented, or not, static friction. By implementing the methods, it was concluded that static friction detection analysis is intuitive, i.e. That their result does not depend on a value or a constant, therefore text boxes were added in the different interface tabs, which describe the conditions under which the presence of static friction in the system can be concluded to guide the user.

4. Conclusions

The computational tool has a versatility when processing each of the methods and is very easy to use. On the other hand, its function is to detect and analyze whether the closed loop control system under study has static friction, which we can conclude from the results of each method. Which are classified as follows cross-correlation corresponding to the analysis of the graph obtained by overlapping the mv data against the OP data, the method of nonlinearity detection and PV-OP pattern analysis is intended to graph the data of the PV variable against the data of the OP variable, determined if it has static friction, as last would be the method of diagnostics based on the adjustment of curves that aims to adjust the PV-OP or PV-PV data, in this way to determine whether there is static friction or distinguish it from other causes. Predictive Model Control

(MPC) is a useful tool to control processes that handle a large number of input and output variables, usually implemented in chemical and industrial plants, it is especially effective in continuous data readings so it could be a great Contribution to future updates of this computational tool [13]. The results obtained with the methods were validated with the Simulink development tool, which is a visual programming environment, which works in the MATLAB programming environment®, thus validating theoretical and practical. When a stable system was simulated in the environment, compare, and verify that the values obtained in the GUI are accurate. Otherwise, it was guaranteed that they would not be invasive so as not to alter the processes, the tool describes the performance of the driver. On the other hand, stable system tests were carried out to validate and verify each of the methods. As stiction normally occurs in control valves, the work area is normally oil and hydrocarbon industries and to transport various substances the use of pipelines is required, therefore a correct control of the use of these is required. in conjunction with the valves to achieve superior performance, it is recommended to use a predictive control strategy to solve possible problems related to the correct control and operation of pipelines [14].

5. References

[1] Thornhill, nf and horch, a. (2007). Advances and new directions in the detection and diagnosis of disturbances throughout the plant. Control engineering practice, 15 (10), 1196-1206.

[2] C. Pryor, "autocovariance and power spectrum analysis derive new information from process data.," control eng, vol. V 29, no. N 11, pp. 103–106, 1982.

[3] Thornhill, nf and hugglund, t. (1997). Oscillation detection and diagnostics in control loops. Control engineering practice, 5(10), 1343-1354.

[4] Verification, validation, and testing: MATLAB and Simulink solutions. (s. F.). MATLAB & Simulink. Retrieved 10 March 2020, from https://la.mathworks.com/solutions/verification-validation.html.

[5] M. Jelali, control performance management in industrial automation. London: springer, 2013.

[6] Escobar Davidson, L, Rincones Sucerquia, S.S, Diaz Sáenz, c., & Jiménez Cabas, j. (2020, May). Computational tool for the detection and diagnosis of oscillations in a control system. Universidad Autonoma Del Caribe.

[7] Tarantino R., Szigeti F., Colina E., (2000) "Generalized Luenberger Observer-Based Fault-Detection Filter Desing: An Industrial Application". Control Engineering Practice. Julio, pp. 665-671.

[8] Thornhill, nf and horch, a. (2007). Advances and new directions in the detection and diagnosis of disturbances throughout the plant. Control engineering practice, 15 (10), 1196-1206.

[9] N. F. Thornhill and t. H'gglund, "detection and diagnosis of oscillation in control loops," control eng. Pract., vol. 5, no. 10, pp. 1343–1354, 1997.

[10] E. Naghoos, "oscillation detection and causality analysis of control systems", era.library.ualberta.ca, 2016. [online]. Available: https://era.library.ualberta.ca/items/57ba6990-7ddc-4b58-8555-b9ea5ec4b79d/view/b06afee3-316c-48e6-b8b6-f08c3d7a9ae4/naghoosi_elham_201607_phd.pdf. [accessed: 31- aug- 2019].

[11] Jelali, M. (2012). Control Performance Management in Industrial Automation Assessment, Diagnosis, and Improvement of Control Loop Performance. 1st ed. [eBook] Available at: https://www.springer.com/gp/book/9781447145455.

[12] Takahashi, s., tachibana, k., & saito, t. (1991). U.s. patent no. 5,043,862. Washington, dc: u.s. patent and trademark office.

[13] Borrero-Salazar, A. A., Cardenas-Cabrera, J. M., Barros-Gutierrez, D. A., & Jiménez-Cabas, J. A. (2019). A Comparison Study of Mpc Strategies Based on Minimum Variance Control Index Performance.

[14] Cardenas-Cabrera, J., Diaz-Charris, L., Torres-Carvajal, A., Castro-Charris, N., Romero-Fandiño, E., Ruiz Ariza, J. D., & Jiménez-Cabas, J. (2019). Model Predictive Control Strategies Performance Evaluation Over a Pipeline Transportation System. Journal of Control Science and Engineering, 2019.