Eigenvector analysis for the ranking of control loop importance

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Inadequate instrumentation and control engineering staff are not able to ensure that all control loops are operating satisfactory at all times. The large number of loops present on a typical industrial chemical processing plant necessitates the prioritization of control loop maintenance and optimization. Base layer control engineers and technicians often follow a “fighting today’s fire” approach as no definite measure is available to identify the faulty control loops that have the highest effect on overall performance.

Connectivity, historical data and economical attributes should be combined to identify control loops with the greatest influence on profitability and/or stability. This will allow more efficient use of control engineer and instrumentation specialist man hours, in turn leading to safer and more economical plant operation.

The main contribution of this paper is the integration of various known ranking, causal mapping and control loop assessment methods into a tool that can prioritize control loop maintenance on a plant-wide or even site-wide scale. In order to prioritize control loops it is necessary to identify control loops with the largest influence which are performing the worst while having the greatest impact on profitability.

It is proposed that a modified form of the Google PageRank algorithm be used to rank control loops based on their connectivity, interaction and importance scores (weights). This concept has been introduced by Farenzena & Trierweiler (2009) who dubbed the method LoopRank. The application of this method to identify the root cause of induced faults of the simulated Tennessee Eastman problem has been successfully demonstrated (Wilken, 2012).

Wilken (2012) reported a number of anomalies in the calculation of importance scores if the PageRank algorithm when applied in unaltered form to infer importance. These issues were related to an inability to differentiate importance of inputs as well as assigning equal importance to parallel paths. Although workarounds have been proposed, further research into conditions relating to unrealistic results and potential solutions is warranted to increase the robustness of the ranking method.

The ranking algorithm is a generalized eigenvector problem once a suitable connectivity matrix has been identified. Setting up this matrix involves 1) determining the connectivity between process variables and 2) assigning weights and importance scores to the connections between process variables as well as the variables themselves.

The connectivity between process variables can be determined in at least two different ways: 1) Determining causality using data-driven methods and 2) defining connections by making use of known process topology (referring to physical and logical connectivity) information contained in P&IDs (pipeline & instrumentation diagrams) which are normally kept well organized and reasonably up to date.

A number of data-driven methods for determining causality between control loops have been reported in the past. A relatively new method called transfer entropy has been show to produce robust results even in the absence of observable time delays (Bauer *et al.*, 2007). Another prominent method uses cross-correlation to estimate time delays in order to infer the sequence of events and therefore causality (Bauer & Thornhill, 2008). Assigning causality based on these methods follows statistical hypothesis testing whereby the apparent degree of correlation is compared to threshold values obtained by studying correlations between random signals of various sampling length and the desired confidence.

Yim *et al.* (2006) reported on the development of a software package combining plant topology with data-driven performance assessment analysis. It is proposed that a similar hybrid approach is followed in order to generate connectivity matrices for the ranking problem using the data-driven methods mentioned above.

In the Google PageRank algorithm the value of an edge between nodes on a directed graph is considered to be a binary state. In order to refine the sensitivity by which control loops with the greatest sphere of influence can be isolated it is desired to assign some weight instead. These weights can be derived from the causality measured mentioned above. Different weighing strategies will be compared to binary mapping in order to find balance between robust results and engineering effort.

As the objective is not only to identify control loops that have the greatest influence, but to prioritize loops for maintenance instead, performance metric is associated with each control loop. As many industrial operations already employ performance monitoring software the aim is to integrate the connectivity with predetermined performance scores. In addition to performance, safety and profitability triage metric should be associated with each control loop. Depending on the amount of information available this can be either categorical or numerical.

The success and usefulness of the integrated holistic approach to control loop maintenance prioritization will be analyzed by simulated scenarios, industrial case studies and interviews with process experts.

Keywords: Prioritization, maintenance, connectivity, causal mapping, plant-wide

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