A Finite State Machine Framework for Control Performance Assessment

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Extended Abstract

Process control loops undergo a variety of conditions during their routine operation such as setpoint changes, disturbances, slow drifts, etc. in addition to normal operation. Monitoring the control performance of these loops is an important activity to ensure satisfactory operation, reduce variability and equipment wear, and detect problems such as oscillating behavior, sluggish or out-of-control situations.

Although it is a challenge to design a single method that can measure control performance under all situations, several methods exist that determine control performance under specific conditions of the control loop. For example, the popular minimum variance benchmark is designed to measure performance under normal operation only. These methods provide an accurate diagnosis for a specific loop condition (e.g., normal operation, setpoint change or disturbance, etc.) while ignoring situations for which they are not designed.

A possible solution for measuring control performance under different loop conditions using separate methods is to combine them in a finite state machine framework. The finite state machine (FSM) or finite automaton is a framework that allows a simple and high-level design of sequential logic and event triggered functions [1,2]. Execution and interconnection of different methods may be handled using event-triggered logic encapsulated in the state machine design. The proposed methodology allows evaluating control performance under normal operation, load disturbances, setpoint changes, persistent oscillations and detects out-of-control situations using different performance assessment methods. The state machine executes specific performance assessment methods during the conditions for which they are designed and allows proper interpretation of control performance based on the system state and the results obtained from the application of individual methods.

A finite state machine framework is presented in this paper that combines many different methods for measuring control performance under various loop conditions such as setpoint changes, disturbances, oscillations as well as normal operation. The FSM uses routine operating data such as the plant input, output and setpoint values, controller saturation as well as results from individual performance assessment methods to execute state transitions. The output of the FSM is the system state which in turn is used to execute specific methods for evaluating control performance. The FASM framework also allows sharing information between different assessment methods. This FSM based methodology may be implemented online in a field controller, a supervisory controller, or deployed on an operator workstation for evaluating control performance from recorded data.

The FSM proposed in this paper has five states, where each state represents a particular condition of the control loop. The five states are (1) normal operation, (2) load disturbance, (3) setpoint change, (4) persistent oscillations, and (5) out-of-control. The control performance is evaluated using available methods in literature. For example, performance during normal operation may be evaluated using the popular minimum-variance benchmark [3], or a zero-crossings approach [4]. The control response when the plant is subjected to load changes can be evaluated using the methods proposed by [5-7]. Regulatory control performance may be assessed using the methods of [8,9]. Oscillation detection and diagnosis may be performed using any of the methods proposed by [4,10-13]. Thus, the FSM allows use of an appropriate method for diagnosis control performance for different loop conditions.

The proposed FSM approach is applied to three case studies: (1) a simulated nonlinear heat-exchanger, (2) real building air duct static pressure control, (3) and real building duct discharge air-temperature control loop. The control loops exhibited multiple setpoint changes, numerous disturbances and oscillatory behavior. The simulated nonlinear heat exchanger exhibited high gain in the lower part of the plant input and high gain in the upper region. When oscillations occurred in the control loop, the FSM transitioned to the persistent oscillations state and diagnosed nonlinearity as the cause of oscillations. At other times during normal operation, control behavior was found to be sluggish, as indicated by the location of the poles of the identified ARMA model.

The data from a duct discharge air temperature loop of a commercial building contained no setpoint changes, but showed large disturbances, periods of persistent oscillations and out-of-control situations. These conditions were correctly identified and diagnosed using the proposed FSM method. The oscillation diagnosis method [13] indicated that the oscillations were caused by a nonlinear source such as valve stiction and were not due to poor controller tuning.

For the air duct static pressure control loop of a commercial building, intermittent oscillations were detected. These were subsequently diagnosed to be a series of external disturbances caused by opening and closing of downstream variable-air-volume boxes. Two setpoint changes were also observed for this system where the step down response showed good response while the step-up response had large overshoot. This behavior was attributed to nonlinearity in dynamics of the system where the plant has faster response to an increase in its input and a slow response to a decreasing input. The FSM detected these different conditions and reported the correct diagnosis for each condition of the control loop.

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