MINE 432: Industrial Automation and Robotics in Mining

Lecture 9

Advanced Process Control Techniques

While feedback control systems form the heart of automatic control systems, when dealing with more complex control problems such as MIMO (multiple-input-multiple-output) systems as opposed to SISO (single-input-single-output) problems as well as non-linear systems or those in which the process parameters change as a function of external or internal variable, a number of advanced methods have been developed. These include:

- Cascade Control Systems
- Feedforward Control Systems
- Adaptive Control Systems
- Model-based Control Systems
- Interactive Control Systems

Each of these will now be discussed in more detail.

Cascade Control

The features that distinguish cascade control include:

- Two feedback controllers with a single control valve (or other final control element);
- The output signal from the "master" controller is the set point for the "slave" controller;
- Two feedback control loops are "nested" with the "slave" (or "secondary") control loop inside the "master" (or "primary") control loop.

The terminology used to describe the two loops is varied. The following are typically used to describe the two systems: slave vs. master; secondary vs. primary; inner vs. outer. Figure 9.1 depicts a cascade control system to control a complex chemical process.

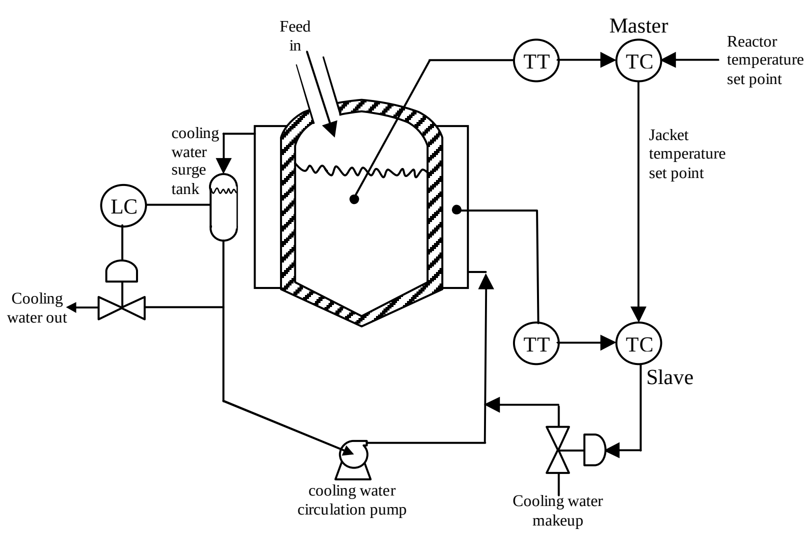

Figure 9.1. Cascade control system for an exothermic chemical reactor.

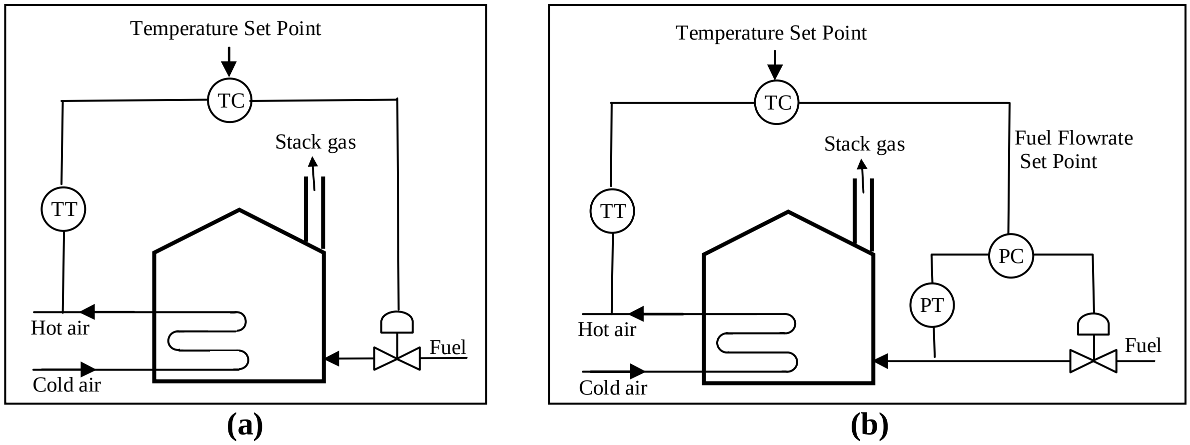

Figure 9.2 A furnace temperature control system: (a) conventional feedback; (b) cascade control.

The most important criteria for cascade control is that the inner loop must have a faster response than the outer loop and preferably as much as double to ten times as fast. The second important aspect of cascade control is that the inner loop be completely enclosed by the outer loop. Should the inner loop cross over the outer loop the probability of instability is significantly increased. Finally, the load changes that enter the inner loop first must be significant. If they are rare or if they are small, cascade control will not provide much overall benefit. Figure 9.3 shows the normal block diagram of a cascade control system.

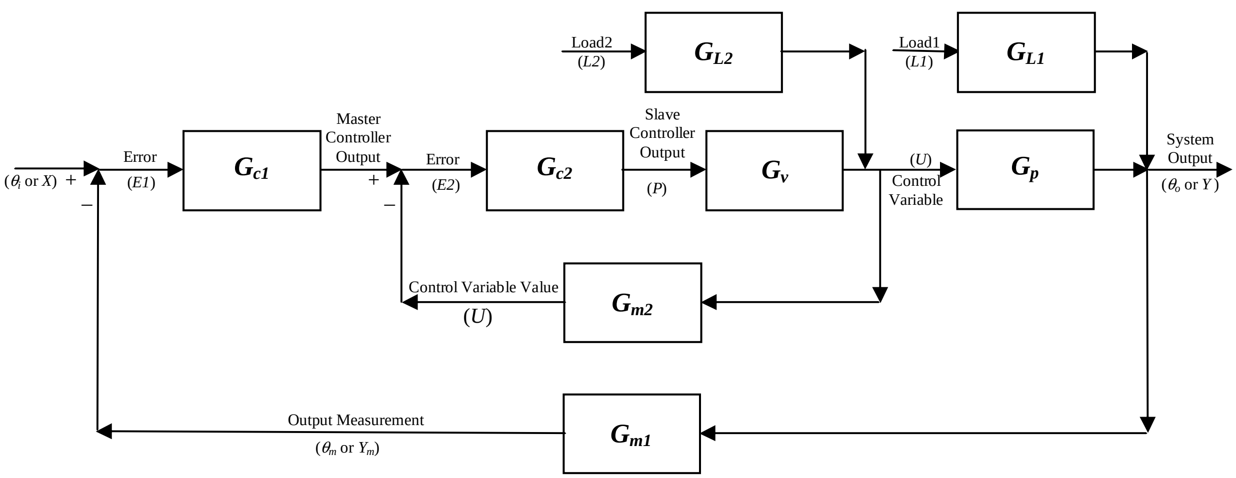

Figure 9.3. Block Diagram of a Cascade Control System.

The load ratio for this system with respect to L_2, the load inside the inner loop is as follows:

$$\frac{\theta_0}{L_2} = \frac{G_P G_{L2}}{1 + G_{C2} G_V G_{M2} + G_{C2} G_V G_{M1} G_{C1} G_P} \tag{9.1}$$

The biggest advantage of a cascade system is the ability of the inner loop to respond quickly to changes in L_1, the load change within the inner loop. Significant improvement in system response can be achieved for regulator control mode using a cascade system. The diagram in

Figure 9.4 shows the dramatic effect of adding cascade control into a conventional feedback PI control system.

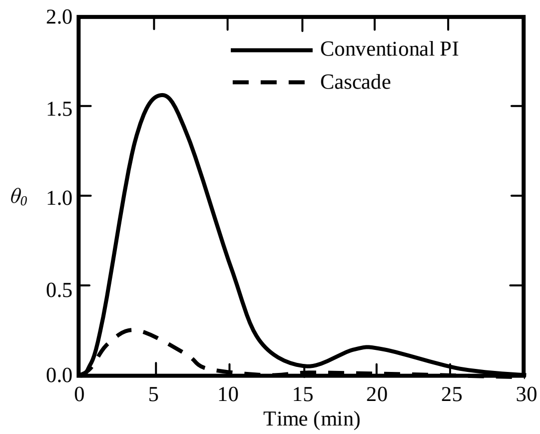

Figure 9.4. Comparison of system response to a step change in L_2 for cascade (K_{c2} = 4, K_{c1} = 3.5, T_{L1} = 5.3 min.) and conventional PI feedback control (K_c = 1.9, T_L = 6 min.).

Feedforward Control

If the process and load block models are well-understood, then it may be possible to institute a type of control known as feedforward. Feedforward control attempts to inform the feedback control system of a change that is anticipated and compensate or optimize the response for such a change. Basically the load change is linked to the set point change through a new control block that is an inverse model of the control system regulator mode. Figure 9.5 shows such a system.

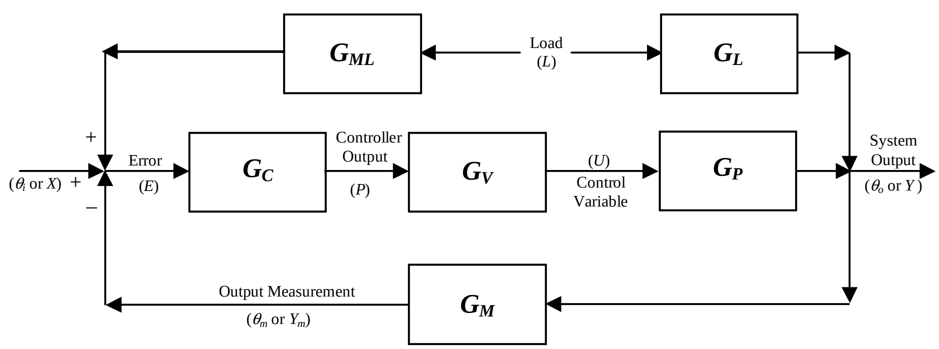

Figure 9.5. A feedforward-feedback control system.

Assume θ_i = 0 (i.e. regulator mode)

$$E = LG_{ML} - \theta_o G_M \quad (9.1)$$

$$\theta_o = EG_C G_V G_P + LG_L \quad (9.2)$$

$$\theta_o = (LG_{ML} - \theta_o G_M)G_C G_V G_P + LG_L \quad (9.3)$$

$$\theta_o = \frac{L(G_{ML}G_C G_V G_P + G_L)}{1 + G_M G_C G_V G_P} \quad (9.4)$$

So if $G_{ML} = -G_L / G_C G_V G_P$ then, in theory, regardless of the type of load change, the system response will equal 0, i.e., Feedforward control can give perfect load compensation. Alternatively, by taking the limit of Eq. 9.4 as s → 0, the gain associated with G_{ML} can be designed (set) to give an optimum steady-state response for a particular load change value. In this case, the controller can remain as a proportional-only controller since the "offset" feature of the proportional-only controller can be incorporated into the optimum response gain of G_{ML}.

Selective Control (Logical-switching)

If the controller is set up in software, there is no reason why the system can't be designed to switch between different strategies. This is often used when one particular variable reaches its limit (either maximum or minimum) and continued control can only be achieved by switching to another manipulated variable. Figure 9.6 shows an example of this type of logical-switching control system.

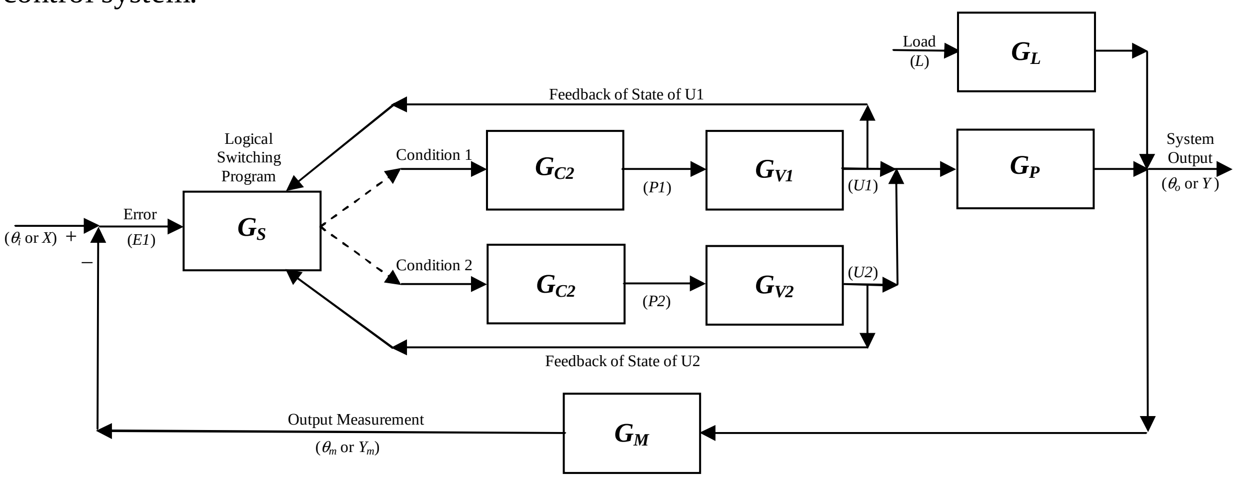

Figure 9.6. An example of a Programmable Logical-Switching Control System (PLC).

So in this system there are two manipulated (or control) variables: *U1*and *U2*. The usual control system changes *U1* as the load or set point changes. However, once the value of *U1* reaches its minimum or maximum value, the Logical Switching Program changes over to *U2* and begins to manipulate this variable as the set point or load changes. At some point, this variable will also reach a value that suggests returning to *U1* as the primary control system. This switching back and forth continues as the two variables interact to produce the desired response to a set point or load change. In this example, both the controller and actuator are involved in the switching. In other cases just the controller may be switched on or off with is akin to an adaptable control system that simply changes the controller parameters according to some schedule. This is often referred to as Gain-Scheduling Control in which a look-up table is created to switch between different controller parameter setting to attempt to maintain satisfactory response.

Adaptive Control

An adaptive control system is totally concerned with the algorithm being used within a single controller block. Basically, adaptive control is able to measure or estimate how the characteristic parameters in the process block are changing (K_p, T_d, and T_p) over time. Such changes may be due to relationships with external variables or they may reflect a non-linear system with respect to the manipulated variable level. As these changes take place (and are measured or estimated), the adaptive control block adjusts the control parameters to attempt to keep the K_c T_I and T_D values on their optimum point with respect to the process characteristics. Figure 9.7 shows an example of an adaptive control system.

An adaptive controller continuously updates and corrects its performance in an environment of changing system or process dynamics by using measurements or signals from the overall process. Adaptation is achieved by: updating the controller parameters from filtered feedback signals; by using a mathematical model to select new controller settings; by adjusting the model equations based on feedback signals; or by modifying the overall control strategy based on model predictions.

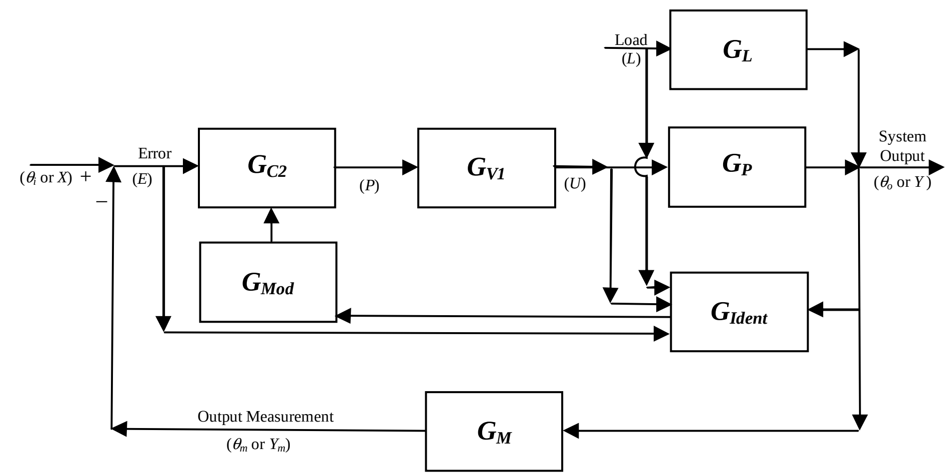

Figure 9.7. An Adaptive Control System.

Note that there are two new blocks introduced into an adaptive control system: a process identification block that determines the changes occurring in the process model; and the modifier block that takes this output and calculates new controller parameter values.

Process identification is the task of obtaining a relationship between all of the process inputs and outputs in a form that describes the behaviour of the system over a wide range of conditions. Automated identification methods are now available on the market that are able to perform tests of a system on-line and from an examination of the output response, generate a model of the process.

Model-based Control

Sometimes called model-reference control, the use of a process model is sometimes used in parallel with the process and instead of feeding back the actual process output variable, the difference between the model output and the actual output is fed back to the controller. This new error is used b y the controller to adjust the controller settings.