NON-LINEAR CONTROL SYSTEM FOR A SINGLE INPUT-SINGLE OUTPUT PROCESS

FIELD OF THE INVENTION

The present invention relates to control systems and more specifically with providing a non-linear control response for a single input single output (SISO) process.

BACKGROUND OF THE INVENTION

It is desirable to automate many industrial or other processes for a number of reasons. For example, the automatic control of the piloting of an airplane is desirable to avoid human fatigue and error over long flights. In many industrial processes such as the operation of a factory, automatic control is preferable to human control since the number of variables and speed of reaction makes human control at times impractical. In other processes, such as the operation of a household furnace, the use of an automatic control is the only practical solution since direct human control would be uneconomic.

In all these control applications, the automatic controller must react to changes in process output operating parameters which in turn will require modification of a process input parameter. Take for example, the household thermostat, the decrease in temperature of the house below a preset temperature causes the thermostat to activate the furnace control. The activation of the furnace eventually causes the temperature in the house to rise beyond the preset temperature, causing the thermostat to deactivate the furnace.

In more complicated systems, a more complex response of the controller may be required. For example, where the initial error in the system is great or has been present for a long time, the response from the controller may be more drastic than where the initial error is slight or recent in time. Similarly, where the error is changing rapidly with time, the response of the controller may be more drastic than if the error is changing slowly. Controllers which are able to react in this way are referred to as proportional-integral-derivative, or PID controllers, and such controllers have dominated industrial controller applications to date. These controllers work by examining the instantaneous error between the process output value and the set point. The proportional term causes a larger control action to be taken for a larger error. The integral term causes a larger control action to be taken if the error has persisted for some

time. The derivative term supplements the control action based on the rate of change of the error.

The value of PID terms depend on characteristics of the process and must be tuned accordingly to yield satisfactory control. Properly tuned PID controllers provide adequate control for a large portion of industrial applications. However, there are many processes with time-variant or nonlinear characteristics which are difficult to control with fixed parameter PID controls. It is well known that conventional PID controllers cannot always control to an "ideal" control response. This limitation is inherent in the linear response of the PID controllers to error stimulus. When the characteristics of a SISO process operation are not linear in nature, a PID controller may not provide the desired accuracy. Varying a process control input does not necessarily mean a process output will vary in a linear fashion. A nonlinear control response to an error stimulus can significantly improve control performance with respect to response time, over shoot and control stability.

Therefore, it is an object of the present invention to provide a non-linear control response system for a single input single output process.

SUMMARY OF THE INVENTION

The invention described herein is a single input single output (SISO) control system which provides non-linear control of an output through manipulation of an input. Included in the system is a sensing means which detects the magnitude of the system output. An error signal generator outputs an error signal which has a magnitude which is proportional to the difference between the magnitude of the output and a predetermined set point. The error signal may also add a term which is dependent on the rate of change of the process output. The sign of the error signal is indicative of the error direction. A lookup table contains a series of entries, each of which corresponds to a particular magnitude range for the error signal. The entries of the lookup table are control signals which are input to the control system to manipulate a control mechanism which varies the magnitude of the input to the process.

In operation, the sensor measures the magnitude of the output of the process. This magnitude is compared to a predetermined set point and an error signal is generated which is proportional to the difference between the output magnitude and a

predetermined set point. This error signal is also either positive or negative depending on the value of the system output in relation to the predetermined set point. The magnitude of the error signal is compared against the series of error signal ranges in the lookup table. Once the particular range is located, the control signal which corresponds to the particular error signal range is then used to vary the magnitude of the input to the process. The lookup table is set up so that the smaller the error signal, the smaller the control signal to change the input. At predetermined intervals a new error signal is generated and a control signal is selected. As the measured output approaches the set point, the step changes in varying the input become smaller and smaller until the ideal operating condition is reached.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of the control system.

Figure 2 is an example of a typical lookup table.

Figure 3 is a graph of the actuator movement versus the magnitude of the error signal.

Figure 4 is a flow chart of the control system operation.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Shown in Figure 1 is a block diagram for a variable air volume (VAV) control system. Although an air flow control system is the preferred embodiment, one skilled in the art would see that the control system described herein could be applied to many other home and industrial applications, one example being temperature control. The VAV system shown is of the single input-single output (SISO) type. The input to the VAV process is the flow control signal and the output is the sensed flow valve. Changing the input of the system has a direct and singular affect on the output.

Included in the control system is microprocessor 10. Incorporated into the microprocessor or stored in separate memory is lookup table 16. In electrical connection with the microprocessor 10 is the flow sensor 12. The mechanical portion 20 of the flow sensor extends out into the air flow. The flow sensor 12 provides a measurement of the air flow rate which is then transmitted back to the microprocessor.

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Also in electrical contact with microprocessor 10 is flow control 14. Incorporated into flow control 14 is a bi-directional electric motor which either opens or closes the valve device 22 in the air flow so as to either decrease or increase the flow rate. Two separate signals are sent out on lines 26 and 28 from the microprocessor in order to either increase or decrease the flow rate. Depending on the signal transmitted by the microprocessor, flow control 14 either opens or closes valve device 22. Also in connection with the microprocessor is set point input 24. This provides a user selected set point for the flow rate.

Lookup table 16 contains a series of control signal values which are used to manipulate the flow control. In this embodiment, the magnitude of the individual entries are proportional to the drive times for the valve motor. The larger the magnitude of the control signal, the longer the valve motor spins the valve mechanism 22 to either increase or decrease the flow. The microprocessor 10 chooses which control signal from the look up table 16 will be sent to flow control 14.

The choice of control signals to transmit to the flow control is made by comparing the magnitude of the flow rate as measured by the flow sensor 12, with the set point input over line 24. In the microprocessor, this comparison is performed and an error signal is generated which has a magnitude which is the difference between the set point and the measured flow rate. The sign of the error signal is indicative of whether the flow rate is too slow or too fast. This comparison of two incoming signals and the generation of an error signal is done by methods and electronic components which are well known in the art. For increased control stability, the error signal may also add a term which is dependent on the rate of change of the process. This error signal derivative term is not necessary in the VAV embodiment.

The look up table is constructed so that the individual entries correspond to a particular magnitude range for the absolute value of the error signal. Once the error signal is generated the microprocessor then scans the lookup table for the appropriate control signal to transmit to the flow control 14. An example of a lookup table is shown in Figure 2. Each entry in the table is a period of time in which the flow valve is to be rotated. For example, the control loop time is 15 seconds and the time periods run from 15 seconds down to 0 seconds. The control loop can be different for different processes to match process response requirements. The control loop can be different for different

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processes to match process response requirements. Above each entry in the look up table is the corresponding error signal range. The larger the error signal the larger the flow control drive time. The significance of this correlation will be described in more detail below. The range for the error signals in this embodiment is from 37-44mV to 1-2mV.

From the polarity of the error signal, the microprocessor will determine whether to open or close the flow valve. Once this determination is made, the control signal is sent over one of two lines. The choice of either line affects the direction of the flow valve movement. For example, if the error signal indicates that the measured flow rate is less than the set point, a signal will be sent out over line 26 to flow control 14 to open the valve. The actual drive time is determined by the value chosen from the lookup table. Conversely, if the flow rate is above the set point, a signal will be sent by the microprocessor over line 28 to valve control 14 to close the valve. The direction of the flow control is dependent on the line the control signal is sent out over.

An important aspect of the present invention is the nonlinear nature of the control system's responses to the error signals. The motivation in designing the present system is to avoid overshooting the set point or oscillations around the set point which is a problem in many linear systems such as PID. The key in creating a nonlinear system is the order and magnitude of the control signal entries in the lookup table.

As was described above, the entries for the lookup table are matched with a particular range of error signals. This alignment is such that the smaller the absolute value of the error signal, the smaller the control signal for driving the flow control. This type of correlation allows the flow rate to approach the desired set point in discrete steps while significantly lowering the chance for overshoot. When the absolute value of the error signal is large, the control signal is large and the valve device 22 is moved in large increments to significantly change the flow of velocity. As the error gets smaller and smaller the valve movements get smaller and smaller so the flow rate slowly approaches the set point.

In Figure 3 is a graph which depicts total valve movement (rotation time) versus error signal magnitude. As is seen, when the error signal is larger, the valve movement is also large. As the error signal gets smaller, the amount of valve movement gets

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smaller in relation. This type of correlation between the error signal and valve movement provides a nonlinear response to process output variations.

The operation of the control system can be better understood by study of the flow chart in Figure 4. The first step in the process is to compare the measured flow rate to a preprogrammed set point. From this an error signal is generated which has a magnitude which is proportional to the difference between a set point and the measured flow rate. The absolute value of the error signal is compared by the microprocessor to a range of values in the lookup table. If the error signal is so small that it does not fit in any of the ranges of the lookup table, the flow rate is sufficiently close to the set point and the control response is no change in process input. If the error signal fits within one of the ranges in the lookup tables, the control signal for that range is retrieved. Next, a determination is made of whether the control signal is negative or positive, which is indicative of the direction of the error. For example, a negative signal indicates the flow is to slow and a positive signal indicates the flow is too fast. Once the proper control signal and direction for correction is determined, the flow rate is then adjusted by driving the actuator accordingly.

The foregoing is a description of a novel and nonobvious, nonlinear, control system for a single input single output control process. The applicant does not intend to limit the invention through the foregoing description but instead define the invention through the claims appended hereto.

We claim:

CLAIMS

1. A single input-single output (SISO) control system comprising:

sensing means to detect the magnitude of the output at predetermined intervals;

error signal generating means to generate an error signal with a magnitude proportional to the difference between the magnitude of the output and a predetermined set point and a polarity indicative of error direction;

a look up table with a plurality of entries, each of the entries corresponds to a range of the error signal magnitudes, each of the entries are a control signal with a different magnitude, the look up table outputs the control signal which corresponds to the magnitude of the error signal input to the look up table; and

means for manipulating the input, said means for manipulating the input receives the control signal and changes the magnitude of the input in direct proportion to the magnitude control signal received and in a direction indicated by the polarity of the error signal.

2. The SISO control system of Claim 1 wherein the sensing means detects airflow rate.

3. The SISO control system of Claim 2 wherein the means for manipulating the input of the system is a flow control valve which controls air flow magnitude in response to an external signal.

4. The SISO control system of Claim 3 wherein the actuator is bi-directional and moves in a particular direction depending on whether the sign of the error signal is negative or positive.

5. The SISO control system of Claim 1 wherein the magnitude of the entries in the look up table for the control signals are proportional to the error signal ranges which correspond to the particular look up tables entries.

6. The SISO control system of Claim 1 wherein said error signal generating means generates an error signal at predetermined intervals.

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7. The SISO control system of Claim 1 wherein the sensing means is a temperature sensor.

8. A method of providing output control in a single input-single output (SISO) system comprising the steps of :

measuring the magnitude of the output from the system at predetermined intervals;

generating an error signal with a magnitude that is the difference between a predetermined set point and the measured magnitude of the output and a polarity which is indicative of error direction;

at the predetermined interval, adjusting the input magnitude in proportion to the magnitude and the polarity of the error signal; and

terminating the input magnitude adjustment when the error signal is smaller than a predetermined amount.

9. The method of input control of Claim 8 wherein the output is flow rate of a gas.

10. The method of input control of Claim 8 wherein the error signal is negative or positive depending on whether the output is greater of less than the predetermined set point.

11. The method of input control of Claim 8 wherein a look up table is provided which contains a plurality of control for changing the magnitude of the input and each of the control signals corresponds to a particular magnitude range for the error signal.

12. The method of input control of Claim 11 wherein the magnitude of each of the control signals in the look up table is proportional to the error signal range the control signal corresponds to.

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