CREDIBILITY TESTING IN SAMPLED-DATA SYSTEMS

Inventor: John P. Mantey, Boulder, Colo.

Assignee: International Business Machines Corporation, Armonk, N.Y.

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References Cited

UNITED STATES PATENTS
3,790,874 2/1974 Klimo 318/327

ABSTRACT

A closed-loop sampled-data servomechanism wherein each sample of the aperiodic feedback signal from a digital transducer is tested to determine if it is credible or valid feedback information. If it is credible, the feedback sample is used as feedback information by the servomechanism. In addition, the valid sample is stored in a memory. Thus, the memory always contains the most recent valid feedback sample. If a particular feedback sample is not valid, the most recent prior valid feedback sample is obtained from the memory and is used by the servomechanism to construct a substitute for the current invalid feedback sample.

4 Claims, 5 Drawing Figures
CREDIBILITY TESTING IN SAMPLED-DATA SYSTEMS

BACKGROUND AND SUMMARY OF THE INVENTION

The present invention pertains to the field of closed-loop sampled-data servomechanisms for use in controlling a process.

More particularly, the present invention pertains to closed-loop motor speed servomechanisms which derive aperiodic speed feedback samples from a digital transducer driven by the motor being controlled.

An inherent characteristic of a sampled-data servomechanism is that a control decision is made at one sample time and, as a result of this decision, a mode of process control is instituted and then maintained, in essentially open loop fashion, until a subsequent sample time. At this subsequent sample time, new feedback information is available and the mode of process control is updated.

The present invention operates upon the principle that whatever the mode of process control, the range of possible subsequent feedback samples can be predicted. If the subsequent feedback sample does not fall within this range, the particular sample is not credible and is classified as invalid. Rather than use the invalid sample to effect a change in the mode of process control, hoping that the invalid sample at least shows the trend in a process variable and any resulting overcorrection will appear in subsequent valid samples, the present invention discards the invalid sample and substitutes a sample based upon the most recent prior valid sample or samples.

More specifically, the present invention provides a testing network or window which tests each feedback sample. Since the validity of a feedback sample is a function of the sample rate and may be variable with other process parameters, the window of acceptable parameter limits is variable with time and may be variable with other process parameters. In one embodiment, the arrival of each valid feedback sample is effective to reset the testing network, in anticipation of the need to test the subsequent feedback sample.

While prior art devices have recognized that failures may occur in servomechanisms, prior art solutions have been in the nature of redundant systems, majority-voting techniques, or the imposition of the requirement that a given feedback condition must be sensed twice or more before corrective action is taken.

The present invention provides the simple control technique of testing the feedback information for validity, and then using the information if it passes the test, or, alternatively, making a substitution based upon the most recent valid feedback if the current feedback fails to pass the test.

The foregoing and other features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic showing of the invention applied to process control;
FIG. 2 is a graph showing the operation of FIG. 1's process variable window;
FIG. 3 is a schematic showing of the invention applied to a speed control process for a direct current motor;
FIG. 4 is a graph showing the contents of FIG. 3's speed memory or store, whose contents define the desired tachometer period, i.e., motor speed, for a start-run-stop sequence, and also showing the acceptable period window, i.e., valid feedback information, which will be accepted and used in the closed-loop feedback system; and
FIG. 5 is a graph showing the contents of FIG. 4's speed command network.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. 1 process 10 is generally shown as having a process variable controller 11, a sampled-data first process variable sensor 12, and a second process variable sensor 17. This general showing of a controllable process is meant to embody a large variety of processes, such as the speed control process of FIG. 3, or, for example, a temperature control process wherein controller 11 compares the output of sensor 12 to a set point temperature and controls the temperature of the process to the magnitude defined by this set point.

The control set point or command for process 10 is received by controller 11 by way of conductor 13. Actual process variable information, corresponding to the set point characteristic, is received by controller 11 by way of conductor 14. Controller 11 is constructed and arranged to compare the command variable magnitude on conductor 13 with the actual variable magnitude on conductor 14 and to institute corrective action within process 10 in order to bring the magnitude of the process variable, for example temperature, to the command magnitude.

Sensor 12 operates to periodically or aperiodically sample the actual magnitude of the process variable and to supply sampled-data feedback on conductor 15 to process variable window network 16.

Network 16 operates to compare the magnitude of each individual feedback sample to a reference magnitude and to make a decision as to whether or not the particular feedback sample is a valid feedback sample or an invalid feedback sample. By definition, a valid feedback sample is a feedback sample which falls within the range of expected values. This range is defined by the range to which controller 11 can achieve change in the process variable. This change is always dependent upon the time between feedback samples, and may additionally be responsive to a second process variable. When the expected range of feedback magnitudes is in fact responsive to and variable with a second process variable, a second process variable sensor 17 is associated with process 10 and provides an output on conductor 18 to control the testing parameter utilized by network 16 to test feedback 15.

If a particular feedback sample passes the required test, this sample is provided as valid feedback information on conductor 19. This valid feedback sample is stored in last valid feedback memory network 20 and is additionally applied to conductor 14 to be used as current feedback information by controller 11. In addition, valid feedback information is effective to reset window network 16, by way of conductor 21, preparing this network for a subsequent feedback sample. Since the ability of network 16 to test a given feedback sam-
ple is time dependent, it is necessary to reset this network to a zero time state such that its testing parameter may again begin its time dependent variation, awaiting a subsequent feedback sample.

By way of example, network 20 may be a register which holds the last valid feedback in binary form. In addition, the output of network 20, which will be used only if subsequent feedback samples fail to pass the test imposed by network 16, may be a substitution which is based upon a most recent prior valid sample or samples. For example, this substituted signal may be a valid sample whose magnitude decays with time.

Assume for the moment that the next feedback sample provided by conductor 15 is in fact invalid feedback, as occasioned, for example, by momentary failure of sensor 12. In this case, this particular feedback sample fails to pass the test imposed by network 16. As a result, conductor 22 becomes active and enables memory network 20 to supply a substitute signal based upon the last valid feedback information contained therein to conductor 14 by way of conductor 23. As a result, process controller 11 continues to control process 10 by using substitute signals based on the last valid feedback information received from sensor 12.

This mode of process control continues until a valid feedback sample is obtained from sensor 12. When this valid feedback sample is obtained, it is stored in memory network 20, it is supplied to conductor 14 for use by controller, and window network 16 is reset to its zero time state, awaiting the next feedback sample.

FIG. 2 is a graph showing schematically the operation of window network 16. In this graph a nominal expected feedback magnitude is represented by broken line 30. At time 10 window network 16 is reset to its zero time state wherein the window test to be subsequently instituted by network 16 is defined by solid lines 31 and 32. By way of example, curve 31 defines the magnitude of the process variable sensed by sensor 12 if controller 11 institutes a 100 percent ON control of the portion of changing portion of process 10 at time 0. This in a temperature control process, for example, would constitute maximum energization of an associated heater, or in a speed control process, would institute full energization of a motor. Curve 32 defines the expected feedback which can occur with variation in time if controller 11 institutes a 100 percent OFF condition of the condition changing portion of process 10 at time 0. It is known that valid feedback information must exist somewhere between curves 31 and 32. Any feedback sample which is either above curve 31 or below curve 32, is invalid feedback information.

Assume for the moment that the next feedback sample is obtained at time 11, and that this feedback sample is valid. This feedback sample is effective to reset window network 16 such that its testing parameters are now defined by broken lines 33 and 34. The testing window defined by these broken lines is identical to the testing window defined by curves 31 and 32, and is time displaced.

FIG. 3 is a schematic showing of the present invention as applied to a process involving the speed control of direct current motor 40. As an exemplary environment of such a process, motor 40 is directly connected to tape drive 41, associated with magnetic recording tape 42. In this environment it is preferable that motor 40 be a high torque - low inertia motor of the type described in U.S. Pat. No. 3,490,672, issued to G. A. Fisher and H. E. Van Winkle.

The feedback sensor in this process is a digital tachometer 43. As is well known to those of skill in the art, such a tachometer provides a feedback pulse on conductor 44 for each unit of rotation of motor 40. By way of example, tachometer 43 may provide 500 pulses for each revolution of motor 40.

The speed of motor 40 is measured by period measurement network 45. This network is effective to count the number of cycles of high frequency clock 46 which occur between adjacent output pulses from tachometer 43. Network 45 utilizes these two inputs to derive a tachometer period measurement, T, on conductor 46.

Capstan motor 40 operates in a start/stop mode and the apparatus of FIG. 3 is operable to control the speed of this motor during acceleration, constant speed run and deceleration of the motor. Speed memory network 47 contains a stored memory of the desired tachometer period, Tr, which should occur during these three phases of a motor cycle. In addition, this network contains a stored memory of the acceptable deviation from this desired tachometer period, this deviation being defined as the acceptable period window ΔTr.

When a start command is received, by way of conductor 48, the accelerate and subsequent constant run contents of memory 47 are interrogated in a continuous fashion, as controlled by clock 49. Subsequently, when a stop command is received on conductor 50, the deceleration portion of memory 47 is interrogated, again as controlled by clock 49.

FIG. 4 shows a representative content of memory 47 wherein solid line 62 represents the desired tachometer period Tr, or command set point for the motor's accelerate, constant speed run, and decelerate intervals. The ΔTr range defined by broken lines 63 and 64 defines the acceptable period window ΔTr. At any given time, the actual period measurement, T, supplied by network 45, must fall within the bounds of broken lines 63 and 64 in order to be classified as valid feedback information.

Period comparison network 51 and period testing network 68 are effective to compare the period feedback information T on conductor 46 with the desired tachometer period information Tr received from memory 47 by way of conductor 52, and with the acceptable period window information ΔTr received from memory 47 by way of conductor 53 to determine if the feedback information is valid and, if valid, to compute the period error Tr for use to control the speed of motor 40.

More specifically, network 68 compares the actual period T to the desired period Tr to determine if the difference between these two periods is less than the acceptable period window. Network 68 may, for example, be an arithmetic and logic unit configured to perform the test |T - Tr| < ΔTr. In other words, equation (T - Tr) < ΔTr must be satisfied. If this test is passed, network 51 is enabled by way of conductor 69. Network 51, which may be a similar arithmetic and logic unit, now computes the period error Tr by way of the equation Te = K(T - Tr), where K is a constant. The computed period error is supplied as valid feedback to conductor 54, where it is stored in hold or memory network 55.

This hold network may provide a steady magnitude signal to output conductor 61. By way of example, network 55 may include a register holding the binary value
of $T_e$, the register driving a bipolar digital to analog converter whose output comprises conductor 61. Alternatively, this signal magnitude or output may exponentially decay toward the expected subsequent period error by providing the predictor network described in U.S. Pat. No. 3,758,757, by O. R. Bühler and J. T. Cutter.

Assuming for the moment that the next sample provided by network 45 fails to pass the test $|T-T_r| < \Delta T_r$, a new calculation of the period error $T_e$ is not made, and the contents of hold network 55 is retained for use by the servomechanism, the invalid feedback information being disregarded.

The apparatus of FIG. 3 includes a speed command network 56 which is controlled by a start command on conductor 57 and a stop command on conductor 58 to provide a signal to power amplifier 59. This signal is selected to normally energize motor 40 to cause the motor to follow a desired acceleration, constant speed run and deceleration profile. The output of network 56 appears on conductor 60 and is summed with the output of network 55 to variably control the energization of motor 40. For example, if the particular feedback sample derived from network 45 indicates that the motor is slow, the output of network 61 is effective to add to the signal provided by conductor 60 and to thereby increase the energization of motor 40. On the other hand, should the motor be fast, the output of network 55 is effective to subtract from the output of network 56 and thereby decrease the energization of motor 40.

FIG. 5 shows the contents of speed command network 56 for the accelerate, constant speed run, and decelerate intervals of the motor. The magnitude of curve 65 is representative of the degree of motor energization which will usually achieve the desired speed profile for a start/stop cycle of motor 40.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A closed-loop speed control servomechanism operable to variably energize a motor in a start-run-stop sequence to achieve a desired acceleration, constant speed run and deceleration profile, comprising:

2. The servomechanism as defined in claim 1 including period comparison network means controlled by said period testing network and receiving as inputs said period feedback data and said desired period data, and operable to supply only valid feedback data to said hold network means, and means connecting the contents of said hold network for use by said servomechanism.

3. The servomechanism as defined in claim 2 including command speed network means, and means summing the output of said command speed network means with the contents of said hold network means.

4. The servomechanism as defined in claim 3 wherein the output of said command speed network means is modified by the contents of said hold network means only when a period error exists.

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