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SWINGING DOOR TRENDING: ADAPTIVE TREND RECORDING?

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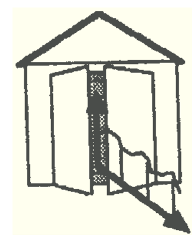
ABSTRACT

In a world of Smart Measurements, Adaptive Control, and Expert System Alarm Managers, one might wonder if there is a place for traditional, stodgy, process control. Surely, Trend Recording will resist change. Not so: new data compression techniques permit computer trending to effectively store and analyze practically unlimited amounts of process history as Trend Records for later evaluation. They compress stored data by orders of magnitude, representing the data as sequences of predefined shapes. The Swinging Door Algorithm is a very simple, effective example of these techniques. It reduces data naturally, as it occurs, to a sequence of optimally chosen straight lines, with a core algorithm that takes, at most, 3 additions, 2 divisions, and 3 comparisons, per sample time, per trended variable.



Not only does this allow reduced memory but, in the long run, it allows the computer to make helpful pattern inferences. When combined with the evermore unlimited capabilities of mass memory hardware, it will not only allow the storage of a complete plant history, but it will provide the ability to search that history for relevant phenomena.

INTRODUCTION

Among the opportunities for expanded process control computer functionality, the one remaining bastion of traditional thinking must be Trend Recording. Here we continue with a digital simulation of the traditional paper record. In fact, as in the case of the early control algorithms (1,2), early digital console trend records seemed not only to copy the methods of their analog predecessors, but to do so with degraded performance. In the execution of the storage of trend records within a limited digital memory, some systems reduced their memory requirements by storing only sampled signals averaged over a fairly long period (e.g., one minute) of time. The resulting trends not only suppressed critical information, but caused the resulting records to look peculiar and thus lose their credibility.

On a different plane, it is useful to be able to store trend data and compress it at the lowest possible distributed system level - even at the loop level. This provides greater data security in the face of equipment failures, a reduced communication load, and local, high-detail storage capability, passing the data to higher level system elements only when needed. This allows monitoring of high-speed process effects or electrical transients that might have degrading effects on the process and its data, and otherwise be difficult to diagnose at a system level. Such a view is compatible with a technology placing ever greater computational power in lower level system components.

The Swinging Door Data Compression Trend Recording System concept described here is one of several developed by the author to solve these problems. Its form is further motivated by the interest shown in some earlier papers on the subject (3). At the core of the system is a method for generating the optimum straight line approximation to a run of trend data. The basic compressed trend record is constructed of a sequence of these straight line approximations. At the cost of greater computation, it can be combined with other methods that increase its direct compression or accuracy further. The efficiency and predictability of this method allows the effective further processing of these sequences, even in the face of quite noisy data, to further compress the data by determining higher level shapes: transients, steps, etc.

Thus it becomes possible to store data greatly compressed, reducing the storage requirement by orders of magnitude, while preserving the credible appearance and relevant detail. The earlier reference (3) describes several methods, each optimized for a particular type of trend recording. One of the benefits achieved by processing for higher level shapes is that it avoids this necessity; the system automatically chooses the most efficient compression method.

The discussion of Trend compression has always been complicated because trend history is data used to solve problems that haven't been understood well enough to, support automated solution. Thus, it has been difficult to define the criteria for the best trend compression scheme. In the end, the proof is in the eating; the Swinging Door System is judged by its flexibility and by the credibility of appearance of the trend records that it generates.

This discussion will briefly examine the roles of trend records in process control. It will present the method and its extensions. It also will show compression results for different kinds of irregular response. Of most importance is a discussion of the practical operational consequences of the system.

THE USES OF TRENDING

There are many standard and recognized uses of trend records. The most obvious of these is to visualize a controller response for tuning. Trend records have been used for after-the-fact product integration and billing. But a trend record is also the only history of changing events. Because of this, there are many other operational and diagnostic uses of trend records. They permit the later recognition of any past event. In the short term, they permit the projection of the trend into the immediate future. Changes in noise level may suggest changes in the process or breaks in the signal wire.

Drifts in measurement may indicate loss of control. Drifts in control signals may represent process degradation. The timing correlation of different trend records may be used to define causality of past events and the progression of some poorly understood disturbance through the plant. All this can be done without very much detail in the response as long as the peaks and valleys of the response can be seen.

There are more unusual and detailed uses of trend records: one of our colleagues has used the visibility of low-level square or triangle waves to locate and diagnose actuator or process hysteresis. But, as with any other tool, a more refined understanding of the function of trend recording can better define the best use of compressed trend recording. Expanding the number and types of variables under trend record and the completeness of record of each variable must expand our ability to track the plant and analyze its performance. Higher level abilities to query a lengthy record of the plant history must make this data more useful.

THE METHOD

The basic method of the system is the Swinging Door Compression Method for obtaining the optimal straight line approximation to a segment of trend data, given an initial point in that line. This method is optimal in two senses: it gives the longest straight line possible for the data, given an allowed maximum error; and it computes this line with the minimum number of computations possible. The core calculation requires, at most, 3 additions, 2 divisions, and 3 comparisons, per sample time, per trended variable. All this is easily proven.

The method is best visualized as depicted in Figure 1. The initial data point (shown on the vertical axis) is positioned with two points, one above and one below, called pivot points. Each pivot point is positioned at a distance E vertically from the initial data point. A straight line, called a door, is constructed through each pivot point.

Each door is initially drawn vertical, or closed, corresponding to a trend record including only the initial point.

But as more and more data points (points A, B, C, D, E, F, and G in the figure) are recorded, the doors are swung open; the top door swinging up and the bottom door swinging down. As each new data point is read in and considered, each door is swung open further, but only to the extent necessary to include that point within the area bounded above and below by the two doors. In Figure 1, points A and B require both doors to open further, whereas points C and D require only that the lower door open further.

Eventually, a point is encountered beyond which the doors must be opened wider than parallel. In Figure 1, this point is E [or an appropriate interpolated point after D (and before E)]. When this point is reached, a parallel midline segment, drawn between the two doors, bounded by the original data point and a vertical line through D, is the desired longest straight line segment. It starts at the initial point and approximates the trend record without exceeding the error-bound E. From the right end of this line, a new line segment may be extended to compress a new data segment.

The process is extended indefinitely to complete the trend record. In Figure 2, a 50 percent offset of E is included between fixed segments. (This is a compromise between the optima for noisy and noise-free signals.) This is one of a series of practical adjustments to the method that can be included in a system design to improve efficiency with real data. (Extrapolate the second segment in Figure 2 to see what it would have done without any offset!) The design stores the trend record as a string of data points (compressed), mixed with mode codes that allow automatic switching between the basic mode of compression, shown above, and other compression modes more efficient for certain types of data:

* Compression with variable bounds, allowing a user-specified lower bound on compression efficiency.

* Direct recording to bypass noisy record sections, where it is clear that the compression algorithm cannot usefully compress the data and simply wastes time and memory.

* Step compression, for those record sections consisting of a series of step changes.

* Persistent cycling.

* Noise or short process pulses in records.

* Etc. (There are many potential extensions, triggered by different record features.)

The Step Mode illustrates the possibilities. In Figure 3, two (noisy)

trend record segments, defined by their end points A, B, and C, have been compressed by the basic method to the three points and their two connecting straight line approximations. The compressed record is then further processed, testing it as a step. This is done by comparing points A and B to see if the line between them is sufficiently long and vertical. The comparison criteria to be met are based on parameters E and T.

If the lines meet the criteria, the two lines will be considered to represent a step and intermediate point B will be compressed out of the record. When the step is to be reconstructed, the vertical is reconstructed as a perfect vertical of width T, starting down from point C, and the horizontal is reconstructed as a perfect horizontal of width 2*E, starting over from point A. Point D is ignored, except in testing for later steps.

It should be clear that the horizontal and vertical tests would be impossible to carry out directly on the original trend record. Thus, the Swinging Door Method is highly useful for "filtering" or abstracting the data to a more useful form, setting up further compression, or pattern matching, for query search.

TEST DATA AND INTERPRETATION

Figure 4 shows detailed sections of noisy, irregular, and stepped trend records as raw data points on top, alone; and below, with superposed compressed line segments shown in terms of the upper and lower error bounds associated with the compression. For the irregular record at the accuracy shown, the compression took a record consisting of 256 points down to 38 points. For the step record, the compression took a record consisting of 256 points and reexpressed it as 3 points. Even more important in the evaluation is the credible and consistent appearance of the compressed records.

The compression achieved depends on the error parameter and the variability and shape of the particular record. However, for a fixed amount of memory, the records can readily be recompressed and flexibly parameterized to achieve any desired trade-off between error bound, sampling rate, number of recorded variables, and length of time recorded. This trade-off is implemented dynamically and automatically under user-specified parameterization.

The computational load of this calculation, per measurement, is on the same order as a controller. The critical calculation consists of the computation of the slopes between pivot points and the current data point, each involving 2 subtractions (1 shared between slopes) and a division. Each slope needs to be compared to the present door slope, replacing it if needed. And any resulting door slope changes also need to be compared to ensure that a new line is not needed. All this requires, at most, 3 subtractions, 2 divisions, and 3 comparisons, per sample, per measurement.

OPERATION

In expanding the amount of trended data simultaneously stored in a control system, the Swinging Door System creates new opportunities and problems. On one hand, the plant record is more complete. On the other hand, there is a larger mass of data. This makes the orderly lookup of data and its effective presentation that much more important. But, returning to the positive, the compressed data allows the lookup of trended data according to its shape. For instance, one can have displayed any transient in a particular variable superposed against all other trend records of variables having transients within a specified interval of time about the original transient.

On a more detailed level, the pattern analysis and other capabilities of this trend recording system concept allow it to do each of the following:

* Integrate trended process event and state data with analog data.

* Support standard groups of trend records associated with user-defined graphic console display plant groupings.

* Allow on-line grouping of any set of process variables for group trend display.

* Allow a separate display of grouped trend records, either separately, each with their scale; or on a single scale, allowing visual correlation of the trends, supporting cause-and-effect analysis.

* Allow a continually updated display of grouped records within a current time window.

* Allow operator specification, by time, of any desired time window for display.

* Allow operator-specified automatic record searches, keyed on recognizable events; arbitrary transients after a steady interval, steps, pulses, cycles, etc.

* Automatic grouping of correlated transients, steps, cycles, or similar commonalities of shape.

* Include a help key on the console to provide display of trend groupings dynamically relevant to particular trend patterns as they are recognized.

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3. Hale, J. and Sellars, H., "Historical Data Recording for Process Computers," Chemical Engineering Progress, Nov. 1981, pp. 38-43.

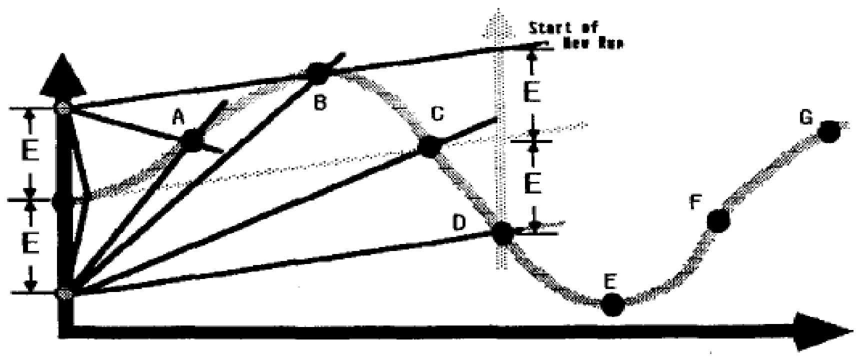

Fig. 1. Swinging Door Compression

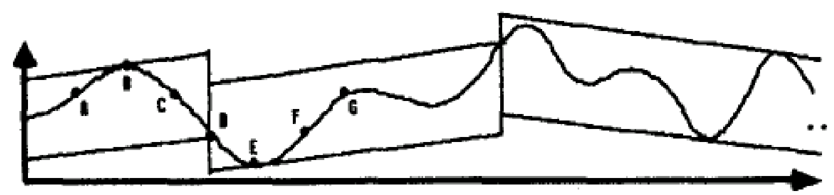

Fig. 2. Compressed Trend Record

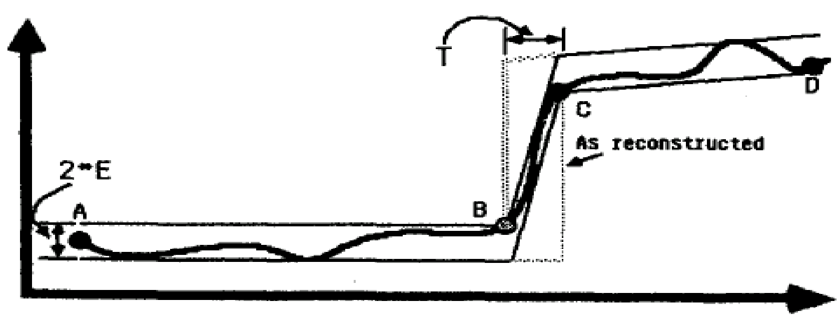

Fig. 3. Step Compression

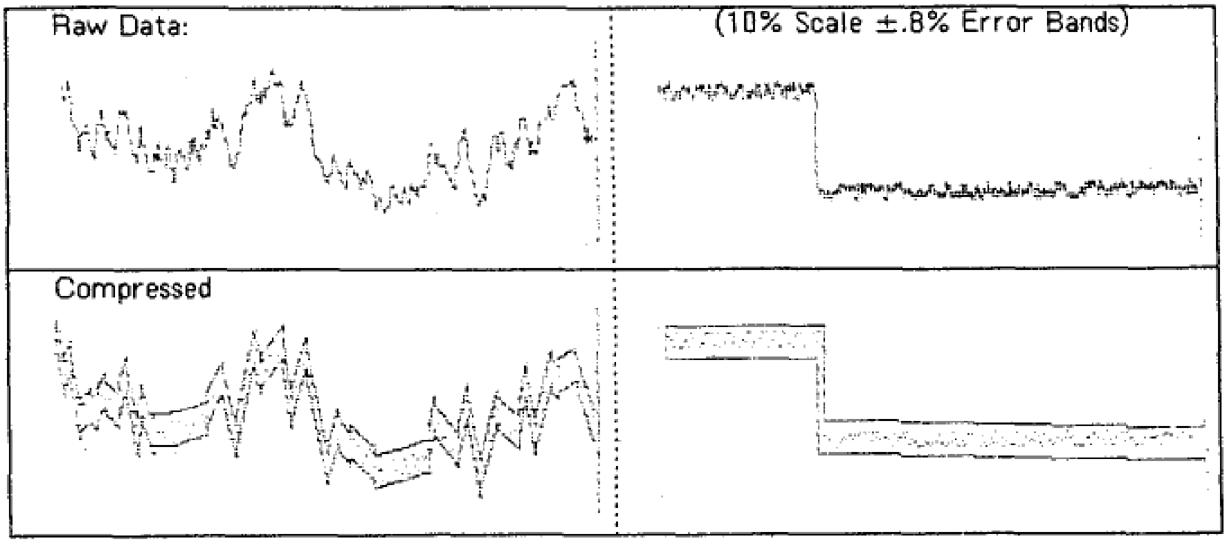

Fig. 4. Irregular and Step Experimental Trend Data