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Title: FUZZY SPC FILTER FOR A FEED-FORWARD CONTROL SYSTEM FOR A THREE-PHASE OIL FIELD CENTRIFUGE

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Fuzzy SPC Filter for a Feed-Forward Control System for a Three-Phase Oil Field Centrifuge

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ABSTRACT

In this work we describe a signal filter for a feed-forward controller based on the application of fuzzy logic combined with statistical process control (SPC). The feed-forward controller is for a three-phase oil field centrifuge. The centrifuge system is used to separate meta-stable three-phase emulsions consisting of oil and water stabilized by solids. These emulsions are considered to be unusable wastes and must be disposed of in an environmentally acceptable manner. The centrifuge is capable of turning these wastes into clean saleable oil, water that can be reused in an operating process or re-injected into oil wells and, solids that can be disposed of in landfills.

The feed-forward controller is used for feed disturbance rejection. It works in conjunction with and, is capable of over-riding the actions of, a feedback controller. The measured feed variables for the feed-forward controller each exhibit reasonably large random fluctuations. It is therefore quite important to use a signal filter that truly recognizes the difference between random noise and a "caused" event, in order to prevent over-riding a perfectly good correction from the feedback controller.

KEYWORDS: centrifuge, fuzzy logic, feed-forward control, signal filter, statistical process control (SPC)

INTRODUCTION

The three-phase centrifuge used in this study is a one-of-a-kind portable system used in oil fields to recover oil and eliminate wastes from tank bottoms. These wastes are not considered hazardous. The centrifuge system is also used in refineries to recover oil and eliminate waste from refinery residue. These wastes are often considered hazardous. The feed to the centrifuge system is quite different in each of these cases. In fact, the feed in the oil field can vary dramatically from field to field as it also does from refinery to refinery. This variable feed requires an adaptable filter for the signals to feed-forward controller.

In addition to the fact that feeds vary from site to site, they can also change dramatically during even a single day of operation at any one site. Feed changes in the past have sometimes been so dramatic that they have actually plugged the centrifuge and shut the system down because operating parameters were not changed quickly enough by the operating feedback control system.

We need the system to respond to true changes and not to noise. The sampled systems are quite noisy and therefore there is noise in the sampled variable. There is also sensor noise. In order to differentiate between true change and noise we implemented an SPC control chart technique. The control charts used in this case were *Individual* and *Moving Range* charts. Initial control charts are established each day at the beginning of a run as soon as steady-state operation is established. An average *Individual* sample is determined from a run of about thirty samples. Control limits are established about the average value. The operator can set these limits for specific feed conditions, or use standard two and three sigma limits. An average *Moving Range* and upper control limit is also established. These control charts are usually used for just one variable. In our case we must measure three dependent variables, feed flow rate change, feed heater power requirement change, and the change in the feed basic sediment and water (BS&W) content. We must then determine if the combination of changes are noise or real feed property changes. For this purpose we use a fuzzy rule based system to determine a value for the *Feed-Change-Magnitude.* This is the value used with the control charts. If the *Individual* values stray beyond the control limits, the *Feed-Change-Magnitude* is considered to be significant and the feed-forward control is implemented. If the *Moving Range* data go beyond the control limits, it usually means a rapid short-term change or that sensor difficulties are coming into play. The *Moving Range* chart is available to the operator, but currently no automatic control action is implemented based on *Moving Range* data.

THE FUZZY-SPC FILTER

The filter is designed to prevent the feed-forward controller from acting upon feed changes that are really just system "noise". The filter is an implementation of a fuzzy version of the statistical process control (SPC) charts known as *Individual* and *Moving Range* charts. These charts were patterned after more commonly used X bar-R charts. Dr. Walter Shewhart [1, 2] developed both types of control charts for quality control in the 1920s. The X bar-R charts and their fuzzy analogs are discussed in more detail by Parkinson [3]. Figures 1 and 2 show an *Individual* chart and a *Moving Range* chart, respectively. These charts were developed using a computer model of the centrifuge feed system and a random number generator, rather than proprietary field data. In practice the SPC version of this technique works quite well [4-6]. For this work and the information displayed in Figures 1 and 2 we have modified the SPC technique to include fuzzy logic. The reason for the modification is that the expert operator normally looks for indications that the feed BS&W has changed by a magnitude of at least ±10% before implementing a manual feed-forward control. The control system can measure this with the feed BS&W meter. However, this is not the whole story. The feed water concentration and feed solid concentration can change in opposite directions, making the feed BS&W reading lower than ±10%. The feed-forward controller relies on knowledge of the water and solid changes individually, not the total BS&W change. A fuzzy soft-sensor determines the magnitude of the individual water and solids changes from knowledge about feed pump flow changes and feed heater power requirement changes in addition to the total feed BS&W change. Our fuzzy filter incorporates these three variables into a single variable that we call *Feed-Change-Magnitude.* This is the variable used with the SPC technique rather than just the feed BS&W change. In our situation, these charts are developed in the field each workday at the beginning of a run, after steady-state operation has been achieved.

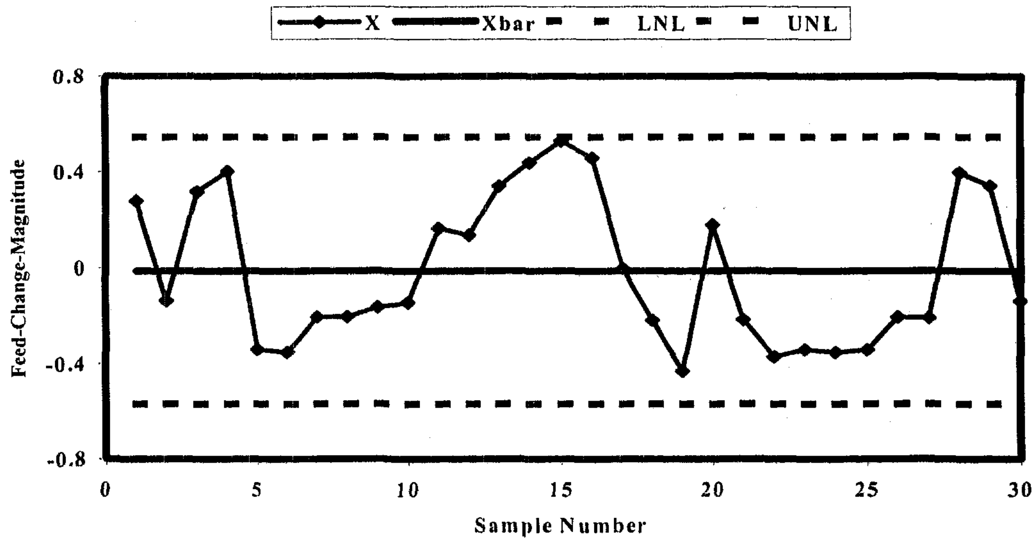

Figure 1. The *Individual* chart for *Feed-Change-Magnitude* for the fuzzy-SPC filter.

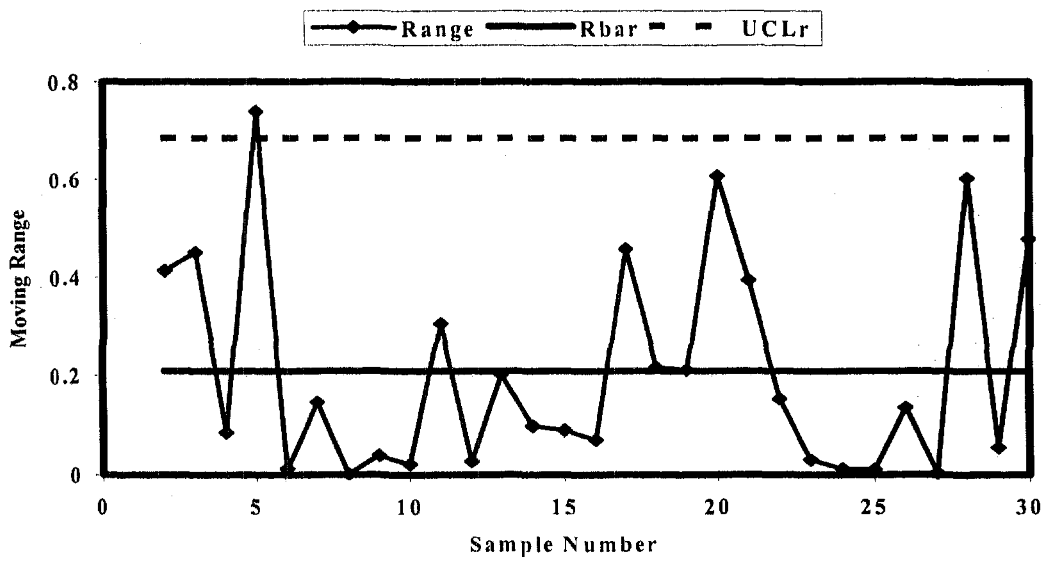

Figure 2. The *Moving Range* chart for the fuzzy-SPC filter.

The *Individual* and *Moving Range* charts are constructed in the following manner:

- Data sets, consisting feed pump flow, heater power requirements, and feed BS&W, are taken at a specified sample interval (depending upon the current centrifuge operation—currently from 10 seconds to about a minute.) If a temperature change occurs the sample is corrected for temperature. The differences in each succeeding set for the three variables are computed. These differences are called *Variable Changes* e.g., *Feed BS&W Change.*
- The *Variable Changes* are used with fuzzy rules represented by the subset shown in Table I, and the corresponding input and output membership functions, to produce the variable called *Feed-Change-Magnitude.* This is the *Individual* variable that is plotted in Figure 1. At each step, the difference between the current *Feed-Change-Magnitude* and the previous *Feed-Change-Magnitude* is computed. This is the *Moving Range* value plotted in Figure 2.
- After thirty sets (five minutes to half an hour), the *Individual* and the *Moving Range* averages ($\overline{X}$ and $\overline{mR}$) are computed.
- The upper and lower control limits for the *Individual* chart (sometimes called the upper and lower natural limits, designated UNL and LNL, respectively in Figure 1., are computed from Eqs. 1 and 2. The upper control limit for the *Moving Range* chart (designated UCLr in Figure 2.) is computed from Eq. 3. These control limits are essentially three standard deviations above and below the mean or average lines.
- If the *Individual* values stray beyond the control limits, the *Feed-Change-Magnitude* is assumed to be significant and the fuzzy soft-sensor and feed-forward control is implemented.
- If the *Moving Range* data go beyond the control limits, it usually means a rapid short-term change or that sensor difficulties are coming into play. The *Moving Range* chart is available to the operator, but currently no automatic control action is implemented based on *Moving Range* data. This may change in the future.

$$UNL = \overline{X} + 2.660\overline{mR} \tag{1}$$

$$LNL = \overline{X} - 2.660\overline{mR} \tag{2}$$

$$UCLr = 3.268\overline{mR} \tag{3}$$

Figure 1 shows that the feed composition generated by the computer model does not stray beyond the control limits. This means that the fuzzy soft-sensor and the feed-forward controller would not be activated by any of the information generated by the computer model for this example. However, the trend indicated by points 12 through 16 show the system was moving "out of control" in that time interval. In Figure 2, the *Moving Range* chart, the point generated from sample number five is beyond the upper control limit. This comes from an abrupt but small reverse in sign for the change in the feed BS&W. With actual data this could be an early warning of an impending feed composition change.

The *Feed–Change-Magnitude* is computed with a fuzzy rule based system. One reason for using the fuzzy technique is the multi-variable nature of the feed. Four input variables are used by the soft-sensor to compute two output variables, percent change in water, and percent change in solid, required by the feed-forward controller. All four of those variables, feed temperature, feed flow rate, feed BS&W, and feed heater requirements, exhibit random noise and they are not independent. It is easy to correct for the feed temperature change. If necessary, the temperature correction is made and then the other three *Change Variables, Feed Flow Rate Change, Feed BS&W Change*, and *Feed Heater Requirement Change* are used with the fuzzy rule base to compute the *Feed-Magnitude-Change.* There are twenty-seven rules, three input variables, and nine input membership functions, one output variable, and five output membership functions in our fuzzy system. The rules are of the form:

If the *Feed Flow Rate Change* is... and the *Feed BS&W Change* is... and the *Feed Heater Requirement Change* is...Then the *Feed-Change-Magnitude* is...

All of the input membership functions are ternary—*Positive*, *Zero*, and *Negative* changes. The output has five membership functions *Large Positive*, *Small Positive*, *Zero*, *Small Negative*, and *Large Negative*. These membership functions are normalized between -1 and 1. All membership functions are described by the simple triangles and trapezoids found commonly in the fuzzy logic literature.

Table I. Some of the Rules for the Fuzzy-SPC filter.

Rule No.	If (Feed Flow Rate Change) is	and (Feed BS&W Change) is	and (Feed Heater Requirement Change) is	Then (Feed-Change-Magnitude) is
1	Negative	Negative	Negative	Large Negative
2	Negative	Negative	Zero	Large Negative
3	Negative	Negative	Positive	Small Negative
. .	. .	. .	. .	. .
13	Zero	Zero	Negative	Small Negative
14	Zero	Zero	Zero	Zero
15	Zero	Zero	Positive	Small Positive
. .	. .	. .	. .	. .
25	Positive	Positive	Negative	Small Positive
26	Positive	Positive	Zero	Large Positive
27	Positive	Positive	Positive	Large Positive

The upper and lower natural control limits shown in Figure 1 are 0.5449 and –0.5692, respectively. Currently, we are using these values as the control limits for a "go" or "no-go" decision for feed-forward control adjustment. We can use any value we wish for the actual control limit, but we will get too many "false alarms" if the actual control limits are smaller than the ones used here.

Table II lists four "disturbance" process conditions, which were generated by the simulation code. These conditions were all intended to pass through the fuzzy-SPC filter to the feed-forward controller. The last column in Table II is the *Feed-Change-Magnitude*. The numbers in the last column are either greater than 0.5449 or less than –0.5692.They would fall outside of the dotted lines shown in Figure 1. Sample numbers three and four would not have passed the normal SPC filter test with the expert operator's criterion of ±10% change for the feed BS&W. The feed-forward controller should act upon these samples since the individual feed water concentration and feed solid concentration varied significantly. The expert operator, using manual control, might possibly determine these changes to be significant by noticing changes in other process variables, and apply appropriate control action. The automatic system has to work with very carefully spelled out directions in order to do at least as well as the expert operator.

Table II. Simulated Feed Conditions and Operating Parameters with the Computed *Feed-Change-Magnitude* that Allowed Passage Through the Fuzzy-SPC Filter.

Sample No.	Flow Rate Change (gpm)	Feed BS&W Change (%)	Heater Power Requirement Change	Percent Water Change	Percent Solid Change	Feed-Change-Magnitude
1	-0.9868	-15.0	-24.9072	-10.0	-5.0	-1
2	-0.5730	-10.0	-7.3806	0.0	-10.0	-0.7793
3	0.0909	10.0	0.0142	0.0	10.0	0.5611
4	1.5198	5.0	33.7269	10.0	-5.0	1

CONCLUSIONS

Other techniques are available for filtering the input and sensor noise. We feel this one is the best for this situation. It provides us with a technique for withholding a significant process change unless it is actually needed and provides us with a record of the process feed changes. If the changes are slow enough they can be handled with the feedback system entirely. More abrupt changes will require the feed-forward system intervention. We can also determine changes in sensor noise and hopefully determine in advance if we are having sensor problems. The control charts are continually and automatically upgraded during the process operation

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