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State Recognition and Prediction of a Batch Culture Using Fuzzy Rules

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Abstract

The purpose of this work is to build a fuzzy model of a batch culture for a process control. The process is highly nonlinear system with large delay. This paper presents two methods of modeling the process behavior. One is a method of recognizing them by fuzzy rules that are contracted by the pattern analysis in consideration of skilled operators' way. The other is a method of predicting them by approximate linear models and fuzzy rules by statistic analysis.

1. Introduction

In general, it is difficult to build a mathematical model of a batch culture, because the reaction scheme of the process is complicated mechanism. The process is highly nonlinear system with large delay. In many cases, measurable variables are restricted. Therefore, state recognition and prediction are needed for appropriate operation. Skilled operators' intuition and their experience are used in a great part of operation. The intelligent control system that contains their knowledge is indispensable to construct factory automation. Thus, I would try to approach fuzzy logic that is able to treat qualitative information like human's recognition and decision.

In this paper, I propose methods of recognizing and predicting the states of the cultural process by using fuzzy rules. First, I would extract the characteristics of the process from the pattern analysis. The characteristics are not clear, but skilled operators are able to catch them well. Thus, I would extract them in consideration of a method of operators' recognition. Then, some fuzzy rules of the state recognition are constructed. Next, I would predict the state variables from the manipulation variables by the approximate linear models. The flow rate of substrate that is most important control variable can be estimated from the state variables. Some fuzzy rules are constructed by statistic analysis. Finally, the effectiveness of these methods is verified through the experimental results.

2. Cultural Process

The industrial aim of the process is the production of the specific chemical substance by culture. The state behavior of the process is very indistinct, because the cultural condition in process reaction is not optimal for cell growth. This process is batch system. In normal state, temperature, pH and substrate (carbon source) concentration is controlled constantly by each PID controller. Temperature is controlled by flow control valve of cooling water. pH is controlled by flow control valve of nitrogen source. Substrate concentration is controlled by flow control valve of substrate.

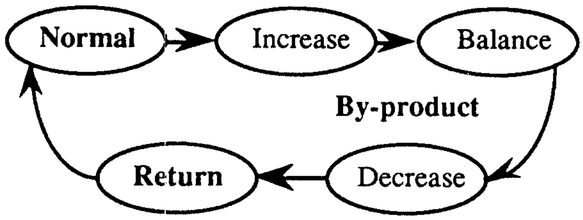
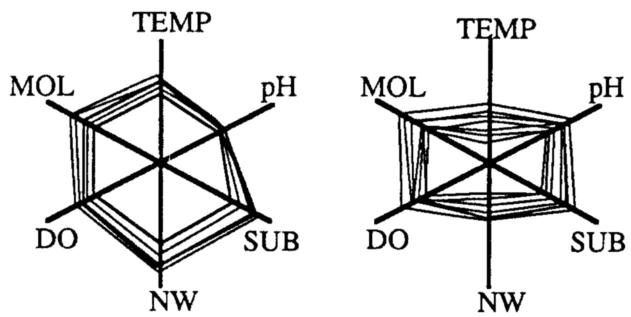


Fig. 1 State transition of cultural process

Fig. 1 shows the state transition of the process. The cell metabolism of normal state in this process is the following scheme. The cells absorb carbon source, nitrogen source, a small quantity of minerals and oxygen. They produce the specific chemical substance and the energy for cell growth, and they excrete heat, carbon dioxide and water. It is not difficult to set the condition for keeping the above metabolism, but the unstable condition for cell growth is needed for producing much specific substances. As a consequence, the process state often changes to metabolism that produces by-products that inhibit normal cell growth. If this state is continued, cells do not produce the specific substance. In worst case, cells die out by chemical characteristics of the by-products. Therefore, the operator manipulates the above control valves to stop progress of the by-products state and to return to the normal state of cell growth.

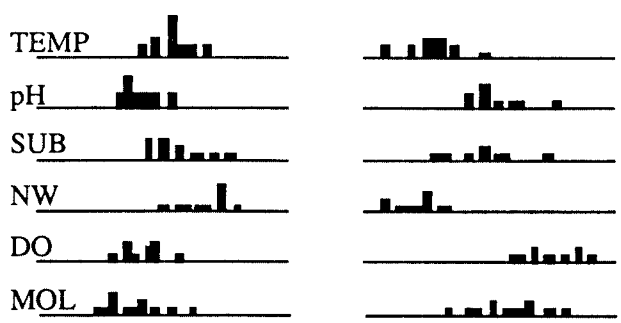
3. State Recognition

First, it is necessary to consider a method of skilled operators' recognition of process state for extracting state characteristics. The operators watch recorders and indicators of measured variables. They understand the state characteristics from the behavior of the above variables. Therefore, I would extract the state characteristics from the pattern analysis. Measurable variables are temperature (TEMP), pH (pH), flow rate of carbon source (SUB), flow rate of nitrogen source (NW), dissolved oxygen (DO) and substrate concentration (MOL). I gathered the time series data of the variables. Then, I classified data to the process state by operators' recognition. Some data sets by the state are constructed. Thus, I made the radar charts from the classified data. One chart includes the data sets of the same state. In this case, the chart is hexagon, because the data set includes the above six variables. Many hexagons are plotted on the same chart. I connected the maximum values of each variable and the minimum values of each variable. The data sets of the same state are included between the maximum hexagon and the minimum hexagon. As a result, the chart means the pattern of the state characteristics. However, the charts can not show the distribution of the data. Thus, I make the other graph that is histogram of the data in the same state. Fig. 2 and Fig. 3 show the example of the radar chart and the histogram. The regions of the same variable in some state are overlapped, but the pattern forms are different clearly. Therefore, it is possible to discern the state by the characteristic patterns.



a) Increase of by-product b) Decrease of by-product

Fig. 2 Pattern of state characteristic



a) Increase of by-product b) Decrease of by-product

Fig. 3 Distribution of data

Next, it is necessary to design fuzzy rules and membership functions. The regions of the variables in one state are defined according to the width between the maximum hexagon and the minimum hexagon. The possibilities of belonging to one state are defined according to the distribution of the data. Thus, membership functions are designed and labeled according to the regions and the possibilities. The premise part of rules is constructed label sets of membership functions that are adapted to the characteristic pattern. The consequence part of rules is constructed from the name of the process state. As a result, some fuzzy rules of the state recognition are constructed. Fig. 4 shows the example of the above design method of fuzzy rules.

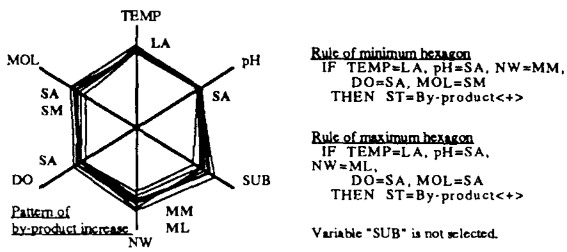


Fig. 4 Design method of fuzzy rule

Finally, I have verified the validity of the state recognition by using the designed fuzzy rules. Fuzzy inference method is max-min composition and defuzzication is calculated by the center of gravity method. Fig. 5 shows the results of the state recognition. The number of experimental data is 1088 and the number of correct results is 959. The rate of correct results is about 88 %. The recognition of fuzzy inference agrees well with the operators' recognition.

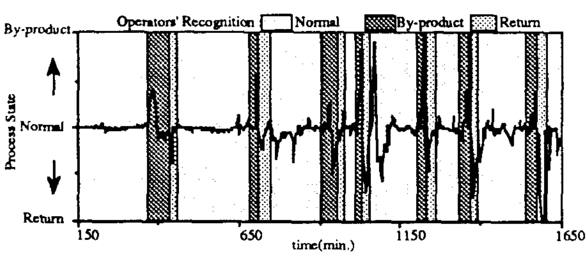


Fig. 5 Result of state recognition

4. State Prediction

The most important variable in the process operation is the consumption flow rate of substrate. In the actual process, the guideline of substrate is defined from the past records of operation. Skilled operators control the process according to the guideline. If the actual flow rate deviates from the guideline, the operators manipulate the control valves. In this case, it is necessary to predict the flow rate for decision of the control values. Therefore, I constructed the block diagram for prediction and estimation. Fig. 6 shows the block diagram. The state variables are predicted from the manipulated variables by transfer functions. The flow rate of substrate is estimated from the state variables by fuzzy inference.

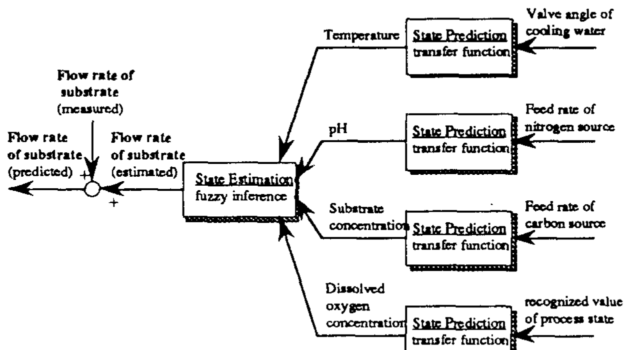


Fig. 6 Block diagram of prediction and estimation

First, I design transfer functions from the actual data of operation, because the parameters of functions are very indistinct. I identify ARX models with high order and optimize them according to constant reactions. Then, transfer functions with low order are constructed. Fig. 7 shows the example of prediction by using designed transfer function. The step of prediction is 15 minutes.

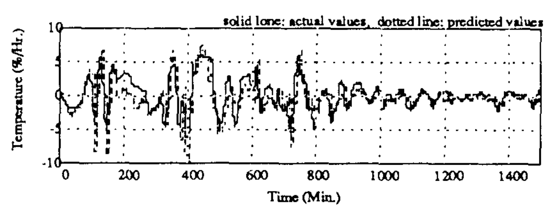


Fig. 7 Result of prediction by transfer function

Next, the target variable that is the consumption flow rate of substrate is estimated by the above predicted state variables. I design membership functions by the statistic analysis of the process data and I design fuzzy rules of estimation by the label sets of maximum adapted membership functions. I designed 160 rules from 7500 data sets. The examples of rules show the followings.

1: IF TEMP=SA, PH=SM, DO=MM, MOL=MM
THEN SUB=SA

2: IF TEMP=SA, PH=MM, DO=MM, MOL=SM
THEN SUB=SM

3: IF TEMP=SM, PH=SM, DO=MM, MOL=SM
THEN SUB=MM

4: IF TEMP=MM, PH=MM, DO=SM, MOL=ML
THEN SUB=ML

5: IF TEMP=ML, PH=LA, DO=ML, MOL=SM
THEN SUB=LA

(SA is small, SM is medium small, MM is medium, ML is medium large and LA is large.)

Finally, the prediction value can be calculated by adding the estimated value and measured value. Fuzzy inference method is max-min composition and defuzzication is calculated by the center of gravity method. Fig. 8 shows the example of the prediction. This result is the prediction of 15 minutes, when the process maintains the present state. The result agrees well with the actual behavior.

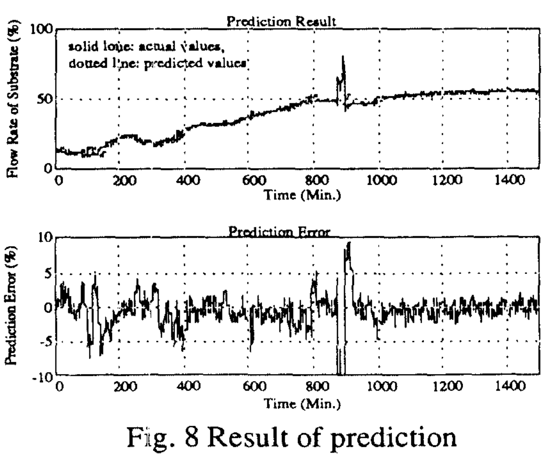


Fig. 8 Result of prediction

5. Conclusion

I proposed a method of the state recognition by using fuzzy rules from the pattern analysis and a method of the state prediction by using fuzzy rules from the statistic analysis. Then, fuzzy system that was designed by using the methods was applied to a batch culture and the effectiveness of these methods was verified through the experimental results.

Acknowledgment

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