COMMERCIAL APPLICATIONS

by

Masaki Togai
Togai InfraLogic, Inc

Fuzzy Logic Workshop
14 November 1990
Nihon-zone

I'd love to vacuum under ordinary circumstances, but I'm sorry to say I'm just not in the mood today.

The programs being aired are totally unsuitable for viewing, so I really must make the decision to take the day off...

I was really thrilled when I first bought all these fuzzy-logic appliances — you know, they approximate human judgment and subjective choice — but now I'm not so sure...

Since this conversation is taking a turn for the worse, I'll have to end it momentarily.

Leigh & Leigh

I have determined that your hair is not quite wet enough to be properly dried. I don't want to wash it again.

After examining your laundry, I've come to the conclusion that it's not quite dry enough to be properly washed. I don't want to wash it again.
Fuzzy Logic

Is Well Suited For Handling

Non-Linear, Time-Varying, and/or Ill-Defined Problems
Japanese Companies Employing Fuzzy

<table>
<thead>
<tr>
<th>Company</th>
<th>Application</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canon</td>
<td>SLR camera focusing, Stepper control</td>
<td>P</td>
</tr>
<tr>
<td>Casio</td>
<td>Clean room temp &amp; humidity control</td>
<td>P</td>
</tr>
<tr>
<td>Daidan</td>
<td>Gas cooling plant</td>
<td>P</td>
</tr>
<tr>
<td>Fujii Electric</td>
<td>Chemical mixer</td>
<td>P</td>
</tr>
<tr>
<td>Hitachi</td>
<td>Waste burning plant</td>
<td>P</td>
</tr>
<tr>
<td>Idemitsu</td>
<td>Sendai Subway control</td>
<td>P</td>
</tr>
<tr>
<td>Ishida Instruments</td>
<td>GaAs crystal growth</td>
<td>P</td>
</tr>
<tr>
<td>Leon Auto Machinery</td>
<td>Automatic measuring</td>
<td>P</td>
</tr>
<tr>
<td>Nippon Steel</td>
<td>Food processing</td>
<td>P</td>
</tr>
<tr>
<td>Maruman</td>
<td>Iron mill control</td>
<td>P</td>
</tr>
<tr>
<td>Mycom</td>
<td>Golf club selection</td>
<td>P</td>
</tr>
<tr>
<td>Meiden-sha</td>
<td>Robotic controllers</td>
<td>P</td>
</tr>
<tr>
<td>Minolta</td>
<td>Dredging control</td>
<td>D</td>
</tr>
<tr>
<td>Mitsubishi Chemical</td>
<td>Machine control</td>
<td>P</td>
</tr>
<tr>
<td>Mitsubishi Electric</td>
<td>Camera focusing</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Cement kiln control</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Elevator control</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Plasma Etching</td>
<td>P</td>
</tr>
<tr>
<td>Mitsubishi Heavy</td>
<td>Air-conditioning systems</td>
<td>P</td>
</tr>
<tr>
<td>Matsushita (Panasonic)</td>
<td>Temperature controllers</td>
<td>P</td>
</tr>
<tr>
<td>Nissan Motor Company</td>
<td>Automatic transmission</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>ABS braking system</td>
<td>D</td>
</tr>
<tr>
<td>Nuclear Power Corp</td>
<td>Nuclear power plant control</td>
<td>D</td>
</tr>
<tr>
<td>Omron</td>
<td>Factory controllers</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Robotic controllers</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Camera stabilizers</td>
<td>D</td>
</tr>
<tr>
<td>Ricoh</td>
<td>Camera focusing</td>
<td>D</td>
</tr>
<tr>
<td>Sanyo</td>
<td>Voice Recognition</td>
<td>D</td>
</tr>
<tr>
<td>Seiko</td>
<td>Camera Iris control</td>
<td>D</td>
</tr>
<tr>
<td>Subaru</td>
<td>Design expert system</td>
<td>D</td>
</tr>
<tr>
<td>Toshiba</td>
<td>Automatic transmission</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Elevator control</td>
<td>D</td>
</tr>
<tr>
<td>Yamaha Seisecities</td>
<td>Product design expert system</td>
<td>D</td>
</tr>
<tr>
<td>Yokogawa Electric</td>
<td>Stock trading</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Digital measurement systems</td>
<td>P</td>
</tr>
</tbody>
</table>

P - Production
D - Development
SU宜ABLE APPLICATION AREA
OF FUZZY THEORY

<table>
<thead>
<tr>
<th>Problems of conventional approach</th>
<th>Suitable Problems</th>
<th>Classification problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Man-Machine Interface Problem</td>
<td>Time-varying dynamics/non-linear problem</td>
<td>Action to be taken is not clear</td>
</tr>
<tr>
<td>• Difficult to express control objectives numerically</td>
<td>• Plant dynamics varies in time</td>
<td>• Cannot describe all solutions for possible patterns</td>
</tr>
<tr>
<td>• Evaluate the control result by human feeling</td>
<td>• Plant is non-linear</td>
<td>speed/hardware limitations</td>
</tr>
<tr>
<td>Applications</td>
<td>Temperature control of A/C, plant, etc.</td>
<td></td>
</tr>
<tr>
<td>Sendai subway</td>
<td>Position control of a hard-disk head</td>
<td></td>
</tr>
<tr>
<td>Suspension control</td>
<td>Auto-cruise</td>
<td></td>
</tr>
<tr>
<td>Crane control</td>
<td>Automatic transmission</td>
<td></td>
</tr>
<tr>
<td>Hand-written character recognition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic transmission</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CHARACTERISTICS OF FUZZY CONTROL

TOP VIEW

VARIABLES

PARALLEL/DISTRIBUTED CONTROL

OBJ 1

OBJ 2

OBJ N

TOGAI INFRALOGIC, INC.
KYOTO-1
CHARACTERISTICS OF FUZZY CONTROL

- PARALLEL/DISTRIBUTED CONTROL

- PRODUCTION RULES (IF-THEN)
  - SIMPLE KNOWLEDGE REPRESENTATION
  - MIXED PREMISE EVALUATION
  - EXCEPTION HANDLING

- QUALITATIVE EXPRESSIONS

IMPROVEMENT ON QUALITY & ROBUSTNESS

TOGAI INFRALOGIC; INC.
KYOTO-1
FUZZY CLOSED-LOOP CONTROLLER
Mitsubishi Heavy Air Conditioner

April 1988 First Design

Simulation by Summer

Production October 1989
Mitsubishi Heavy Air Conditioner

Room Heating and Cooling Times Reduced by 5X

Temperature Stability Increased by 2X

Overall Power Savings of 24%

Reduced the Required Number of Sensors
FUZZY INVERTER
AIR CONDITIONER SYSTEM

- TEMP. SENSOR
- TEMP. ERROR
- TEMP. CHANGE
- FUZZY INFERENCE
- INVERTER FREQ.
- COMP. VALVE
- FAN SPEED

- 50 RULES (HEATING&A/C)
- MAX-PRODUCT INFERENCING
- DEFUZZIFICATION: CENTROID METHOD

TOGAI INFRALOGIC, INC.
Mitsubishi Heavy Air Conditioner

Graph showing temperature and inverter frequency over time.
Mitsubishi Air Conditioner

外気温 0℃

圧縮機周波数 Hz

時間 分

—— ファジイ制御
—— 従来の制御
考察

FUZZY2(振動を起こす)
FUZZY1(安定・即応)
PID(従来)

操作量

入力値
Automatic Train Operation System Based on Fuzzy Control

Introduction

Regular research of the automation of train operation began in around 1960 in Japan, and various tests with real cars were conducted for confirming functions of basic elements such as constant speed automatic operation, train automatic stop control at predetermined location, and train interval control.

In the last half of the 1960's, ATO devices were applied to the test cars for the Shinkansenbullet train and the monorail vehicles for the 1970 World Exhibition held in Osaka, Japan.

Starting from 1988, ATO devices for remote control were adopted in diesel hydraulic locomotives operated in steel works, and saving labor and securing safety were realized.

In the 1970's, the ATO devices were used in many subway cars and vehicles of automated guideway transportation systems, and many improvements were made.

Recently, research on application of fuzzy control to automatic operation of subway cars was started. Venue service of the subway line of Sendai Municipal Transportation Bureau was started in July, 1987, and smooth and accurate automatic operation has been realized by employing ATO devices based on fuzzy control.
PREDICTIVE FUZZY CONTROL

CONTROL PURPOSE

FUZZY CONTROL RULES

OBJECTIVE DIFFERENCES

CONTROL COMMAND

STATE & OBJECTIVES PREDICTION

FUZZY INFERENCE

PROCESS

ACTUAL STATE

SENDAI SUBWAY CONTROLLER

TOGAI INFRALOGIC, INC.
KYOTO-5
The Sendai Subway System

Structure of Fuzzy ATO algorithm
The Sendai Subway System

First Proposed to the Government 1978

Granted Permission to Operate After:
3,000 Empty Subway Runs
300,000 Simulations

Began Operation in 1986

Hitachi Granted Contracts for Tokyo Subway 1991
The Sendai Subway System

Performance Improvements

Improvement in Stop Gap by 3X

Reduction in Power Settings by 2X

Overall Reduction in Power by 10%
The Sendai Subway System

Outline of automatic train operation

- Limited Speed
- Target Speed
- Automatic Train Control Equipment
- Traceability
- Running Time
- Energy Consumption
- Safety
- Comfort
- Target Position
- Stop Gap
- Station

PS1: CSC Position Marker
PS2: TASC Position Marker
Distance
The Sendai Subway System

ATC Wayside System
(Automatic Train Control)

ATS System
(Automatic Train Supervision)

Train detection and Signaling

Supervisory Command

ATO Onboard System

Traction Controller

ATC Onboard System

Brake Controller

Distance Pulse

Cab Signal

Tacho Generator

Track Circuit Position Marker

Typical configuration of ATO
The Sendai Subway System

Table 1 Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>t</td>
<td>time (sec)</td>
</tr>
<tr>
<td>x(t)</td>
<td>location of train (m)</td>
</tr>
<tr>
<td>v(t)</td>
<td>velocity of train (km/h)</td>
</tr>
<tr>
<td>N(t)</td>
<td>control command notch</td>
</tr>
<tr>
<td>X(t)</td>
<td>target position of next station (m)</td>
</tr>
<tr>
<td>V_t</td>
<td>target speed (km/h)</td>
</tr>
<tr>
<td>T_t</td>
<td>predicted running time (sec)</td>
</tr>
<tr>
<td>X_d</td>
<td>forward location where the maximum speed limit is lower (m)</td>
</tr>
<tr>
<td>t_s</td>
<td>time to reach X_d point (sec)</td>
</tr>
<tr>
<td>X_k</td>
<td>ending location of coasting (m)</td>
</tr>
<tr>
<td>X_Z(v)</td>
<td>beginning point of TASC zone (m)</td>
</tr>
<tr>
<td>t_Z</td>
<td>time to TASC zone (sec)</td>
</tr>
<tr>
<td>t_c</td>
<td>elapsed time from last notch change (sec)</td>
</tr>
<tr>
<td>N_c</td>
<td>degree of last changed notch</td>
</tr>
<tr>
<td>N_p</td>
<td>control command notch to be selected</td>
</tr>
<tr>
<td>V_p(N_p)</td>
<td>predicted speed when N_p notch is selected (km/h)</td>
</tr>
<tr>
<td>V_e</td>
<td>velocity allowance range (km/h)</td>
</tr>
<tr>
<td>X_p(N_p)</td>
<td>predicted stop position if N_p notch is selected (m)</td>
</tr>
<tr>
<td>X_e</td>
<td>allowance of stop gap (m)</td>
</tr>
</tbody>
</table>
The Sendai Subway System

Subway acceleration

- Computer controlled
- Human controlled

Source: Togai InfraLogic Inc.
Theory of Fuzziness & Fuzzy Control

The theory of fuzziness was first proposed in 1965 by professor L.A. Zadeh of the University of California at Berkeley.

The theory of fuzziness deals with a set with ambiguous boundary instead of an ordinary set. In the conventional Boolean set comprising "0" and "1," the boundary of an individual set can be clearly distinguished, but the fuzzy set is characterized by the fact that the boundary between the inside and outside of the set is not obvious.

The fuzzy control is based on the fuzzy set theory which was developed for determining the quantity of subjective fuzziness of human being and for making objective evaluation of the fuzziness possible, and thereby eliminating fuzzy portions as much as possible.

In the conventional automatic operation system, train operation is performed by a control based on PID Control (Proportional, Integral, and Differential Control) so that target speed pattern determined for each operating section can be followed. In this conventional automatic train operation, accurate operation can be achieved in a manner of following the predetermined speed pattern.

However, in actual practice, there are many kinds of changes of running conditions such as gradient etc. of track and the braking force of rolling stock. Therefore, to follow the target speed, it is necessary to send control commands frequently for acceleration and brake application. As a result, smooth operation is apt to become difficult, and riding comfort is likely to be degraded. Moreover, an accuracy of train stopping at predetermined locations of stations cannot be determined through the logic of the control system. Accordingly, dispersion should be checked by computer simulation or tests using real cars.

This kind of problem occurs because the train operation characteristics as a controlled system are not well adapted to its control system. The characteristics of running train vary complicatedly and non-linearly in response to changes in the external situation. In the conventional control method, complicated controlled systems, were dealt with approximating them to simple linear models, and only the follow-up to predetermined speed pattern was taken into account in the evaluation related to control. That is, the conventional control was unable to properly respond to changes in the situation.

On the other hand, in the fuzzy control, the results of running operations being considered are predicted in advance as the same as actual decisions made by a human operator.
The Sendai Subway System

Stop-Gap and Power Settings
Nissan Close To Introducing Fuzzy Logic Transmission Controller

Soon—in the next year or so—Nissan will start selling cars programmed with a new, extra smart transmission control, popularly known as fuzzy logic. Speculation is that inference-based control logic will debut on Nissan's 300 ZX, the company's premier performance car, and perhaps on its Infiniti Q45 luxury sedan. Industry Analyst Roger Stetsak, San Jose, CA, reported Subaru and Mazda are seriously pursuing the same smart control technique. He predicted a two- to three-year time frame for this to happen, at most.

Like Nissan, Subaru will apply fuzzy logic to transmission control. Mazda is testing it for application in collision avoidance systems. In Mazda's case, Stetsak expected a long lead time, as much as ten years, since legal approvals for its system will require extensive testing.

Hiroshi Takahashi, research engineer at Nissan's Central Engineering Laboratories, Yokosuka, Japan, said Honda and Isuzu are working on fuzzy logic for automotive electronic controls as well. Engine control, with its constraints.

Please, see Fuzzy Logic, p. 12

WHAT A DIFFERENCE: More shifting, less comfort. Honda studied shift scheduling and found that gears were shifted less when the transmission was controlled by fuzzy logic rather than a traditional program. The comparison charts come from a paper (#905049) presented by Honda Research and Development Engineers Sakai, Araki, Hasegawa, Sakaguchi and Iwaki at the International Federation of Automotive Engineering Societies in Turin, Italy, in May. Call the Society of Automotive Engineers, Warrendale, PA, 412-775-4841, for a copy.
Automatic Transmission

Objectives:

Smother Ride

Increased Fuel Savings

Less Wear
1. KNOWLEDGE BASE
   (IF...THEN...)

   SENSOR
   INPUT BLOCK
   REASONING BLOCK
   OUTPUT BLOCK
   AT
Automatic Transmission

Shift (Drive)

Shift (Fuzzy)

Velocity (Km/h)

Time (SEC)
Nissan Patents 'Fuzzy Logic' ABS, Gearbox

By ANGELA G. KING

TROY, Mich. — Nissan Motor Co. Ltd. has received U.S. patents on an anti-lock brake system and a transmission that incorporate "fuzzy logic" computer programming.

Designed to automate human reasoning, fuzzy logic programming offers various possible solutions, using graded or qualified statements, to a problem rather than the precise yes-or-no solution of strict logic widely used in the electronics industry, according to Lofti A. Zadeh, who first developed the concept of fuzzy reasoning in the mid-1960s.

Mr. Zadeh is currently a Professor of Computer Science in the Electrical Engineering and Computer Science department at the University of California at Berkeley.

A Nissan spokesmah said engineers are still developing the brake and transmissions systems, and no introduction dates have been set. Nissan has developed a fuzzy logic program and is now looking to see if it can be applied to its patented transmission and brake system designs, he explained. Fuzzy logic programming, according to the company, would enhance brake and transmission system performance with improved control flexibility.

Nissan is developing an automatic transmission in which fuzzy logic computer programming is used to electronically shift gears in a manner similar to a driver who weighs different factors to manually shift gears.

WITH A CONVENTIONAL automatic transmission, electronic sensors detect vehicle speed and throttle opening, and gears are shifted based on the predetermined value of these factors. According to Nissan, this type of system is incapable of always providing satisfactory control performance to a driver because it provides at most only about three different shift patterns.

But the Nissan fuzzy control transmission, (patent number 4,842,342), is more flexible and provides a driver with more control performance because it is operated by sensors that assign values to numerous variables, including vehicle speed, throttle opening, acceleration and the rate of change of the throttle opening. Each value is given a weight, and the weights are calculated to make the decision on whether to shift gears.

Where conventional ABS incorporate sensors that detect vehicle and wheel speed, the Nissan system's (patent number 4,842,342) control unit measures these variables in addition to derivatives of wheel speed with respect to time and derivatives of vehicle speed with respect to time. As in the transmission, certain signals in the brake system are assigned weighted values that determine the frequency of ABS brake actuation.

In a paper entitled "Making Computers Think Like People," Mr. Zadeh explained that fuzzy logic allows computers to handle such imprecise human concepts as "small," "big," "young" and "old" by describing them in ranges of numbers instead of exact terms.

DEVELOPMENT OF FUZZY logic in the early 1970s by Ebrahim Mamdani, a control engineer at Queen Mary College in London, and Seto Assilian, Mr. Mamdani's student at that time, has led to growing interest in the use of this theory in such applications as industrial process control and automobile engine control, said Mr. Zadeh.

Japan in particular has shown a great deal of interest in fuzzy logic. Research is being conducted in Japan in the application of this system in such areas as vehicle control at the Tokyo Institute of Technology's Sugeno Laboratory, and robot control at Hosei University's Hirota Laboratory.

In March, Japan's Ministry of International Trade and Industry established the Laboratory for International Fuzzy Engineering Research (LIFE), a group that consists of 48 member Japanese firms, including Nissan.

A fuzzy system developed by Hitachi, also a member of the new LIFE organization, is already used to control subway trains in Sandai, Japan.

Fuji Heavy Industries Ltd., the maker of Subaru cars, is developing an advanced form of electronic continuously variable transmission, called the ECVT-II, that also uses fuzzy control.

The ECVT-II is not in production now and is not expected to appear in an automobile before model year 1991, according to a spokesman at Subaru of America, Cherry Hill, N.J.
FUZZY LOGIC-BASED COMMAND SYSTEM FOR ABS

SUPPLEMENTARY COMMAND HYDRAULIC PRESSURE

COMMAND WHEEL VELOCITY

REGULATOR

HYDRAULIC PRESSURE

HYDRAULIC SERVO

WHEEL VELOCITY

(UNKNOWN)

VEHICLE VELOCITY

FUZZY LOGIC-BASED COMMAND MODUL

TOGAI INFRALOGIC, INC.
KYOTO-6
FUZZY FEED-FORWARD CONTROLLER
FUZZY AUTO-TUNING SYSTEM

Schematic of a fuzzy control system showing feedback loops involving a PID controller, fuzzy inference, and tuning command.