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...

Nihon-zone

Leigh & Leigh

...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...

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

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

After examining your laundry, I've come to the conclusion that I don't want to wash it.
Fuzzy Logic

Is Well Suited For Handling

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

<table>
<thead>
<tr>
<th>Company</th>
<th>Applications</th>
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<tr>
<td>Canon</td>
<td>SLR camera focusing, Stepper control</td>
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<tr>
<td>Casio</td>
<td>Clean room temp &amp; humidity control, Gas cooling plant</td>
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<td>Daldan</td>
<td>Chemical mixer, Waste burning plant, Sendai Subway control, Elevator control</td>
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<tr>
<td>Fujii Electric</td>
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<td>Hitachi</td>
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<td>Idec Izumi</td>
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<tr>
<td>Ishida Instruments</td>
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<td>Leon Auto Machinery</td>
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<td>Nippon Steel</td>
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<td>Maruman</td>
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<td>Mycom</td>
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<td>Meiden-sha</td>
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<td>Minolta</td>
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<td>Mitsubishi Chemical</td>
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<td>Mitsubishi Electric</td>
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<td>Mitsubishi Heavy</td>
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<tr>
<td>Matsushita (Panasonic)</td>
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<td>Nissan Motor Company</td>
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<td>Nuclear Power Corp</td>
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<td>Omron</td>
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<td>Ricoh</td>
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<td>Sanyo</td>
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<td>Seiko</td>
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<td>Subaru</td>
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<td>Toshiba</td>
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<td>Yamaichi Securities</td>
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<td>Yokogawa Electric</td>
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<td>Mitsubishi Heavy</td>
<td>Air-conditioning systems</td>
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<td>Matsushita (Panasonic)</td>
<td>Temperature controllers</td>
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<td>Nissan Motor Company</td>
<td>Automatic transmission</td>
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<td>Nuclear Power Corp</td>
<td>ABS braking system</td>
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<td>Nuclear power plant control</td>
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<td>Ricoh</td>
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<td>Sanyo</td>
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<td>Seiko</td>
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<td>Subaru</td>
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<td>Yamaichi Securities</td>
<td>Camera Iris control</td>
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<td>Yokogawa Electric</td>
<td>Design expert system</td>
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<tr>
<td>Mitsubishi Heavy</td>
<td>Elevator control</td>
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<tr>
<td>Matsushita (Panasonic)</td>
<td>Product design expert system</td>
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<tr>
<td>Nissan Motor Company</td>
<td>Stock trading</td>
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<tr>
<td>Maruman</td>
<td>Digital measurement systems</td>
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</tbody>
</table>

P - Production
D - Development
## SUITABLE APPLICATION AREA OF FUZZY THEORY

<table>
<thead>
<tr>
<th>Problems of conventional approach</th>
<th>SUITABLE PROBLEMS</th>
<th>Classification problem</th>
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</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>Problems of conventional approach</td>
<td></td>
<td></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>Temperture control of A/C, plant, etc.</td>
<td>Aut-iris/auto-focus</td>
</tr>
<tr>
<td>Sendai subway</td>
<td>Position control of a hard-disk head</td>
<td>Hand-written character recognition</td>
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<tr>
<td>Suspension control</td>
<td>Auto-cruise</td>
<td>Automatic transmission</td>
</tr>
<tr>
<td>Crane control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic transmission</td>
<td></td>
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</tbody>
</table>

TOGAI INFRALOGIC, INC.
CHARACTERISTICS OF FUZZY CONTROL

PARALLEL/DISTRIBUTED CONTROL

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
FUZZY CLOSED-LOOP CONTROLLER

Diagram:

- SV → + EV
- EV → Fuzzy Controller
- Fuzzy Controller → MV
- MV → PROCESS
- PROCESS → PV

TOGAI INFRALOGIC, INC.
KYOTO-3
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 RULES
- MEMBERSHIP FUNCTIONS
- DEFUZZIFICATION: CENTROID METHOD
- 50 RULES (HEATING & A/C)
- MAX-PRODUCT INFERENCEING
- MAX-PRODUCT INFERENCEING
- FAN SPEED
- INVERTER FREQ.
- COMP. VALVE

Togai InfraLogic, Inc.
ARTIFICIAL INTELLIGENCE ON A CHIP
Mitsubishi Heavy Air Conditioner
Mitsubishi Air Conditioner

外気温 0℃

圧縮機周波数 Hz

時間 分

ファジィ制御
従来の制御
考察

- FUZZY2（振動を起こす）
- FUZZY1（安定・即応）
- PID（従来）
Automatic Train Operation System Based on Fuzzy Control

Introduction

Regular research on the automation of train operations 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 Shinkansen bullet train and the monorail vehicles for the 1970 World Exhibition held in Osaka, Japan.

Starting from 1968, ATO devices for the Sengai Municipal Transportation Bureau 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. In the tunnel service of the Sendai Subway, the 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

OBJECTIVE DIFFERENCES

Fuzzy Control Rules

Control Command

Actual State

State & Objectives Prediction

Fuzzy Inference

Process

Sendai Subway Controller

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

Structure of Fuzzy ATO algorithm

- $X_d$
- $N(t)$
- $x(t)$
- $V_t$
- $v(t)$
- $X_t$

- Safety
- Comfort
- Energy Saving
- Traceability
- Running Time
- Stop Gap

$N_{PC}$: CSC control comma to be selected

Choice of the Total Control Notch

$N_{PT}$: TASC control comma to be selected
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

- Limited Speed
- Target Speed
- Running Time
- Energy Consumption
- Safety
- Comfort
- Traceability

Outline of automatic train operation
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

Cab Signal

Distance Pulse

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 = (X_Z(v) - x(t))/v(t) )</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

Station stops

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 decision 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 is 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 control system are not well adapted to its control system. The characteristics of running trains 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.
The Sendai Subway System

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

by ANDREA SAXER

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 Steciak, San Jose, CA, reported Subaru and Mazda are vigorously 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, Steciak 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

WHAT A DIFFERENCE: More shifting, less contact. 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 chart comes from a paper (#905049) presented by Honda Research and Development Engineer Sakai, Arai, 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, 412-373-4441, for a copy.

CONCEPTUALLY SPEAKING: The Nissan Arx concept car has a control schema that could incorporate fuzzy logic, according to Hiroshi Takahashi, a research engineer at Nissan's Central Engineering Laboratories, Yokosuka, Japan.

House Committee OKs
100% WHS Funding

Toyota J1850
10 Contract
Automatic Transmission

Objectives:

Smother Ride
Increased Fuel Savings
Less Wear
1. SENSOR

2. INPUT BLOCK

3. REASONING BLOCK

4. OUTPUT BLOCK

KNOWLEDGE BASE
(If...Then...)
Automatic Transmission

Throttle Opening vs. Velocity (Km/h)

- WOT
- 6/8
- 4/8
- 2/8
- 0
- 50
- 100
- 150

- 2
- 3
- 4

Togai InfraLogic, Inc.
ARTIFICIAL INTELLIGENCE ON A CHIP
Automatic Transmission

Velocity (Km/h)

Shift (Fuzzy)

Shift (Drive)
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 spokesman said engineers are still developing the brake and transmission 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 America, Cherry Hill, N.J.
FUZZY LOGIC-BASED COMMAND SYSTEM FOR ABS

SUPPLEMENTARY COMMAND HYDRAULIC PRESSURE

FUZZY LOGIC BASED COMMAND MODULE

COMAND WHEEL VELOCITY

REGULATOR

HYDRAULIC PRESSURE

HYDRAULIC SERVO

WHEEL VELOCITY

VEHICLE VELOCITY

(UNKNOWN)

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

TOGAI INFRALOGIC, INC.
KYOTO-4
FUZZY AUTO-TUNING SYSTEM

FUZZY INFERENCE

TUNING COMMAND

PID CONTROLLER

PROCESS

SV - EV

MV

PV

TOGAI INFRALOGIC, INC.
KYOTO-3