Fuzzy Logic: An Introduction to Fuzziness in Controllers and Decision Making for Engineers

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INTRODUCTION

Individuals, both singularly and collectively, make life-threatening decisions based on incomplete data. Such decision events are common place and, perhaps, occur on a daily basis. Consider approaching a busy intersection on foot (walking), by bicycle or in a motorized vehicle. Further consider there is no traffic signal controlling flow through that intersection. What do individuals do at this decision "node"?

If presented with all the data, can an individual……can all individuals make a safe decision to pass through the intersection? The data required for this analysis would require the location, direction, speed, acceleration and weather conditions for any and all "participants" involved in this area. Perhaps even more data might be needed. Then, the evaluation process (read: complex calculations) can begin…..noting that some data input are functions of time. That is, as more time is needed to process the data, the more likelihood the data inputs change.

In the real world and before proceeding through the intersection, individuals rarely, if ever, consider the data needed for their safety in this situation. What do individuals really do? Roughly, "data" is collected by looking, say, trying to identify approaching vehicles ……. estimating their distances, speed, acceleration …. perhaps more inputs are considered…. perhaps less information is considered…… then, with all this imprecise data, a decision is made.

The real life process just described evaluates local situations and creates inferences. The various inferences are analyzed to make a deterministic action such as proceed or not through an intersection, and such a decision can be for just that given moment in time. In the context of this course, we will apply fuzzy logic to these real world inputs or inferences and we will convert these inferences into "fuzzy sets". The "fuzzy sets" are analyzed to determine the "crisp" go/no-go decision. This is the essence of fuzzy logic.

Human beings have the ability to take in and evaluate all sorts of information from the physical world and mentally analyze, average and summarize all this input data into an optimum course of action. All living things do this, but humans do it more and do it better.

Computers, on the other hand, operate on a binary basis … true or false, on/off. There is comfort in the rigidity of an "on/off" world and in making decisions. The rigidity on how a computer processes or operates appears to be odds with the human decision making process. In humans, the ability to handle ambiguity is even present in our consciousness, possibly evolving over the span of our existence.

The world we live in is full of ambiguities. We may communicate with one another by saying: "The temperature is pretty warm". This statement has meaning between two individuals both in its raw form as well as in any context where/when the statement was made. The statement, however, cannot be evaluated as strictly true or false. We accept that this statement has certain ambiguities.

As the complexity of a system increases, it becomes more difficult and eventually impossible to make a precise statement about how data impacts that system's behavior. As complexity increases, the need to process data requires better ways to evaluate inputs to realize some decision. This is where fuzzy logic is applied to computer processing, among other areas.

Thus, the mathematical theory of fuzzy logic was developed. The theory of fuzzy logic states that rather than a statement being true or false, each statement has a certain confidence level. For example, a confidence value of 0.000 meant false and a confidence value 1.000 meant true. A statement "this room is warm" might have a confidence value of 0.700 at 80 degrees. Note that confidence level is not an absolute number as the same confidence level (0.700) can describe a room at 30 degrees if that room were, say, at a research station in Antarctica.

If you think about it, much of the information you take in is not very precisely defined, such as evaluation of the behavior of a vehicle entering from a side street and the likelihood of the vehicle pulling in front of you. This information or data (or "quasi data") is called fuzzy input. Some of this "input" is reasonably precise and non-fuzzy such as your speedometer reading. Other data is imprecise and, at time, unknowable!

Yet an individual processing of all this information can make a binary decision: either proceed or not. This is called fuzzy processing. Fuzzy logic is the way the human brain works. This fuzzy logic can be incorporated into "binary machines" like computers allowing such machines to perform somewhat like humans.

BASIC DEFINITIONS

Some preliminary definitions are provided and utilized throughout this presentation. What is different in the fuzzy logic arena is that individual data points are allowed to be grouped in multiple sets or subsets. One example might be the term "Ambient temperature of 75 degrees". This defined data point may fall into the category of "too hot inside" for a winter day, "too cold inside" for a summer day and "ideal outside" for a spring day. It is the idea that data points may be in multiple set which gives fuzzy analytics/processing its flexibility.

CRISP DATA or CRISP DECISIONS

Define CRISP DATA as precisely defined input. Examples might be: 5.2 inches, 8 ft. in length, 45 m.p.h., 15 / 8 (Cartesian coordinates on an X-Y axis). Each of these examples are defined as single data points…..so 5.2 inches is not the same as 5.25 inches or ">" (greater than) 5 inches or less than 6 inches. Crisp data contains no ambiguity or allows any ambiguity.

Define a CRISP DECISION as decision that has no ambiguity. "Proceed" might be a crisp decision and "proceed down this road/path" is even more descriptive. Turning a switch from on to off, or remain as is, can be examples of crisp decisions.

Use the following crisp data for the following examples;

Sally (female)

Age: 14 (today is Sally's birthday)

Height: 4' 5"

Weight:

Hair color: Dark Blonde

Eye Color: Blue eyes

Introduction to Some FUZZY TERMS

Fuzzy logic can be applied to crisp data above … in essence, it is said that the data can be "fuzzified". From a fuzzy point of view, Sally can be described as "not tall" compared to the entire population on earth or extremely tall compared to all members of her class in her current grade school.

Back to the initial notion of set participation, membership in any given set can be categorized from the scale of 0.000 to 1.000, where Sally is part of every group with some portion of participation. That is, Sally can be described as a member of the group called "female giants" but the confidence level applied is extremely low (say 0.015). These confidence levels are based on the 'degree of truth'.

Further definitions include

- Crisp Facts – distinct boundaries
- Fuzzy Facts – imprecise boundaries
- Probability - incomplete facts
- Example – An advanced infantry scout reporting on an enemy.
  - "Two to three tanks at grid NV 123456" (Crisp)
  - "A few tanks at grid NV 123456" (Fuzzy)
  - "There might be 2 tanks at grid NV 54" (Probabilistic)

The concept to keep in mind is that even sets themselves may have fuzzy definitions or imprecise non-crisp descriptors.

One further note, fuzzy analysis is not to be confused with reasoning or decision making under uncertainty. Uncertainty generally refers to a probability of realizing some future event where such event is predicted using some known or unknown probability distribution function targeting such events. The probability of a "noon rain shower tomorrow providing 1 inch of rain" might be drawn from a Gaussian, Normal or other distribution defining this event of uncertainty. Referencing the intersection example, the analysis of proceeding safely through the intersection at any time must utilize the probability distributions of when an individual might arrive, when others might be arriving on the cross streets and other "might occur" actions take place. On the contrary, fuzzy decision analysis requires some crisp data such as: the individual is at the intersection, there are others crossing the intersection from one side or the other or both. In this instance, the event is a "now" event where the data from the other inputs, such as motorists crossing the intersection, is not crisp and can be estimated or a fuzzy set can be created.

Background and Some History

The concept of Fuzzy Logic (FL) was conceived by Lotfi Zadeh, a professor at the University of California at Berkeley. Fuzzy logic was developed in the 1960's in order to provide mathematical rules and functions which permitted natural language queries. Fuzzy logic provides a means of calculating intermediate values between absolute true and absolute false with resulting values ranging between 0.0 and 1.0. With fuzzy logic, it is possible to calculate the degree to which an item is a member. For example, if a person is .83 of tallness, they are "rather tall." Fuzzy logic calculates the shades of gray between black/white and true/false.

In 1965 Dr. Zadeh published a paper "Fuzzy Sets" that formally developed multi-valued set theory and introduced the term fuzzy into technical literature.

Dr. Zadeh, as the principal founder of the fuzzy logic theory has earned numerous awards, fellowships and honors and has contributed a large amount of research and publications to the field of knowledge representation. A brief summary of historical steps follows:

1965	Seminal Paper "Fuzzy Logic" by Prof. Lotfi Zadeh, Faculty of Electrical Engineering, U.C. Berkeley, Sets the Foundation of the "Fuzzy Set Theory"
1970	First Application of Fuzzy Logic in Control Engineering (Europe)
1975	Introduction of Fuzzy Logic in Japan
1980	Empirical Verification of Fuzzy Logic in Europe
1985	Broad Application of Fuzzy Logic in Japan
1990	Broad Application of Fuzzy Logic in Europe
1995	Broad Application of Fuzzy Logic in the U.S.
2000	Fuzzy Logic Becomes a Standard Technology and Is Also Applied in Data and Sensor Signal Analysis. Application of Fuzzy Logic in Business and Finance.

E.H. Mamdani is credited with building the world's first fuzzy logic controller, after reading Dr. Zadeh's paper on the subject. Dr. Mamdani, London University, U.K., stated firmly and unequivocally that utilizing a fuzzy logic controller for speed control of a steam engine was much superior to controlling the engine by conventional means.

Using the conventional approach, Dr. Mamdani found that extensive trial and error work was necessary to arrive at successful control for a specific speed set-point. Imagine trying to achieve a specific temperature for a pot of hot water. The stove is cranked up and water temperature begins to rise …… then overshoots the target. The stove is turned down and the temperature drops…... but overshoots now on the low side.

Look at a steam engine as another example. Due to the non-linearity of the steam engine operating characteristics, as soon as the speed set-point was changed, the trial and error system had to be engaged to arrive at a new effective control point. A fuzzy logic system, designed correctly, can execute changes which can almost eliminate any over- or under-shots for system settings.

Interesting "Historical" Side Notes:

There are some interesting nuances about "fuzz", "fuzzy logic" and "fuzzy math" and how the development of this processing logic developed quicker in other nations, even though it originated in the United States.

- The word "fuzzy" has a negative connotation in the US
    - Fuzzy thinking, fuzzballs, fuzzy haircuts, uphill battle with first impression (reminder: fuzzy logic was circa 1960's)
- "Fuzzy" phonetically translates to "smart" in Japanese

Note the two bullet points are not the absolute or only reasons for a lack of initial development of these concepts in the United States. These also don't fully explain why others took this direction as 'first movers'. But the fact that Japan & Asian & Pacific Rim countries have 80% of the patents of Fuzzy related inventions give support, somewhat, to the nuances offered.

What is Fuzzy Anything and Why Do We Care?

Artificial Intelligence

Artificial Intelligence (AI) is a form of computer reasoning (and processing) designed to mimic the human reasoning process. Artificial intelligence may be thought of as the umbrella term for many forms of evolving technology (expert system, fuzzy logic, neural networks). Each of these systems, in some manner, attempts to embody the computer with human-like capabilities. These can include "thinking", "seeing", "hearing", where the process might "see" something, analyze then execute some function based upon what the computer's decisions processor were for that object.

Fuzzy logic is a superset of conventional (Boolean) logic. At the heart of Boolean Logic is the idea that all values are either true or false. Boolean Operators include: "Or," "And," and "Not". Fuzzy logic extends the concept allowing set participation of partial truths – where truth values fall between "completely true" and "completely false".

Fuzzy logic is the attempt at formalization of approximate reasoning, which is a characteristic of the way individuals reason in an environment of uncertainty and approximation. Fuzzy logic holds that all things are a matter of degree.

Fuzzy logic has been used in application areas such as project management, product pricing models, sales forecasting, criminal identification, process control and signal processing. Fuzzy logic is used in system control and analysis design, because it shortens the time for engineering development and sometimes, in the case of highly complex systems, is the only way to solve the problem.

Fuzzy vs Randomness vs Probabilities

Fuzzy logic is a logic of fuzziness, not a logic which is itself fuzzy; analogous to probability. The laws of probability are not random, just as laws of fuzziness are not vague.

Randomness describes the uncertainty of event occurrence. Whether an event occurs can be said to be "random". Generally, event occurrence can be measured, say, using past data which reports how often a particular event happened versus the range of all possible events. Prediction of weather events, such as rain or clouds, is based on historical outcomes in the past with identical or similar current inputs.

- Fuzzy applications will come to understand that "partly cloudy" can mean a degree of sunshine. The probability of a cloudy day is definitive. The degree to which it is cloudy is fuzzy. The degree to which an event occurs can be said to be fuzzy, and to make a more blurred transition between randomness and fuzziness, probability is often applied to fuzzy events: satisfied customers, slight delay, partly cloudy.

Fuzzy Sets, Fuzzy Logic, and Fuzzy Operators

In conventional set theory, on which Boolean logic depends, a particular object is either a member of a given set of objects or it is not. This can be summarized with "crisp" IF statements: IF this, then that….or Not This, then the other.

In a traditional expert or decision system, the rules are "all" or "none" at all. This is because a traditional expert system uses "yes/no," "on/off" logic to evaluate the premise of each rule….the application of a true Boolean logic system.

In contrast, the rules in a fuzzy expert system incorporate the fuzzy rules which produce "shades of gray" responses. In addition, more than one rule may fire for a given group of inputs, so the output of the expert system may be the combined result of several rules. An example of an accelerating car follows. Assume the vehicle speed is relatively low, the engine speed (RPM) is relatively high and the gas pedal is "mashed to the floorboard!". A traditional system might shift the car to a higher gear, where a fuzzy system might keep the low gear just a little longer (to get that extra "pop" in acceleration, indicated by the 'gas pedal' position).

Fuzzy operators allow one to combine differing inputs into premises or rules/applications. The fuzzy logic operators are AND, OR and NOT. For example, assume we operate a 'Big and Tall' gentlemen's clothing store and wish to market to our target market. What is that market? We can say it is all "tall men". But, what "height" do we say…... men above "X" are in our market but below "X" they are not?

If we define "X" as 6' 3", we may be excluding a large population who feel they are tall at 6' 2"! We can apply fuzzy logic works through the use of fuzzy sets so that we include larger population groups in our marketing attempts.

Fuzzification of Data

An example of crisp data being converted into various fuzzy sets is fairly easy to understand. For example, the following has some differing board lengths in a lumber yard:

Very long boards:	12' to 18'
Long boards:	10' to 15'
Almost long boards:	8' to 12.5'

Perhaps the reader has observed or noted that a general category title ("very long boards") has crisp data points for set inclusion (12' or greater but not over 18'). It should be further observed that each general category does not begin/end where another category begins/ends. So, a board with a length of 12' will be a member of the three sets defined above. It is the ability for a data point, say a board of 12' in length, to be in multiple sets or categories which gives "fuzzy calculations" the power and flexibility in decision making.

Even before the creation of fuzzy logic, "fuzzification" of crisp data was evolving. Below is an example of how descriptive words can be converted to crisp data and these charts can also be used in reverse.

	Simpson 1944 Median	Hakel 1968 Median	
Always	99	100	Always
Very Often	88	87	Very Often
Usually	85	79	Usually
Often	78	74	Often
Generally	78	74	Rather Often
Frequently	73	72	Frequently
Rather Often	65	72	Generally
About as Often as not	50	50	About as Often as not
Now and Then	20	34	Now and Then
Sometimes	20	29	Sometimes
Occasionally	20	28	Occasionally
Once in a While	15	22	Once in a While
Not Often	13	16	Not Often
Usually not	10	16	Usually not
Seldom	10	9	Seldom
Hardly Ever	7	8	Hardly Ever
Very Seldom	6	7	Very Seldom
Rarely	5	5	Rarely
Almost Never	3	2	Almost Never
Never	0	0	Never

The ideas of the charts created by Simpson and by Hakel imply that any data can be converted into fuzzy data.

Defuzzification

Defuzzification is the ultimate goal for all fuzzy logic problems. The term "to defuzzify" is the process where inferences, set memberships and other problem parameters create a crisp or deterministic step or action. In controllers, this is the last stage where the controller is to take some action, even if that action is to do nothing at the moment.

The fuzzy data goes through an analysis whereby coded statements or algorithms are applied to the various data sets. These algorithms are generally set up as "if" statements (if this, then that, if not this, then some other outcome). As more features are incorporated into the final controller/decision process, additional "if" statement will be required. The complexity may require "nested 'If' statements" where the embedded "If" statements create additional math calculations as well as offer other options, perhaps, in the controller.

As an example, consider a residential thermostat controlling a central heating and air condition system for a single family home. Further, consider only the heating aspect of the system. Consumers who use the fuzzy logic feature of the controller may set the thermostat for different temperatures for different parts of the day. Continuing, the owner of the home wants to be conservative in heating expenses during the normal sleeping hours (say 11 pm to 6 am) each night. Then, the homeowner wants to wake up to a warm house that is kept warm until 8:15 am, the time when the family members leave for work and school. After this time, the thermostat is to conserve energy by turning down the temperature setting. Later that day, the system is to heat the house for the arrival times of household members as they return from school, work or recreation activities.

The owners of the home may set crisp numbers as to exact temperatures desired at the times they set. Additionally, the homeowner may set a range of temperatures defined as "warm" for these given times. The range of temperatures allows the flexibility to maintain both comfort levels in the home and some comfort in their pocket books. That is, a range of 68 degrees to 71 degrees can be set. When outside temperatures are below freezing, the lower end of the range can provide comfort as well as save on fuel costs during extremely cold days.

Data points are collected, monitored, and analyzed in real time for this residential controller. Algorithms utilizing the homeowner's desired overlay these data and update the fuzzy data sets along with the decision algorithms of the controller. Some of the algorithms incorporate the following:

- What time of day is it?
- What is the current temperature inside the house?
- What is the current 'trend' (over the past 30 seconds, for example) for the inside temperature?
- What is the crisp data point for this time of day? Or, What is the range of temperatures desired at this time of day?
- What is the outside temperature?
- What is the current trend for outside temperature?
    - (Assuming the system has a 'learning' or history feature)
- What is the approximate time needed to raise the temperature (*) from its current state and current trend to the desired temperature or range of temperatures given the outside temperature and trend of the outside temperature?

(*) Note in this residential thermostat, an overshot on inside temperature will result in a dormant system and steps are not taken to cool the air temperature.

That is, an overshot of a warmer home will not create an A/c turning on. Real world fuzzy logic thermostats have the ability to be set where the consumer can get the system to remain off or turn on.

Imagine two back to back days at 4:30 am are compared. Both days have the inside temperature at or near ideal conditions, for that time of day. The early day has outside temperatures at 40 degrees and the second day has outside temperatures. The fuzzy data leading to the fuzzy sets leading to the decision algorithms might show on the first day, the heating system is within parameters for now and can meet future expectations (for 6 am). The second shows that while the heating system is within parameters for now, it cannot meet its future obligations (at 6 am) unless is begins the heating process now. So the same inside temperature does not lead to the same controller decision.

Complex Example

Much of the information an individual takes in is not very precisely defined, such as wind speed, automobile gap distances, stopping distances for their automobile or others, and yet decisions are constantly made. Simply put, this is fuzzy input. Some of your "inputs" are reasonably precise and non-fuzzy such as the speedometer reading. Your processing of all this information is not precisely definable. We call this fuzzy processing.

Suppose you are driving down a typical, two way, 6 lane street in a large city, one mile between signal lights. The speed limit is posted at 45 Mph. It is usually optimum and safest to "drive with the traffic," which will usually be going about 48 Mph. There will be some drivers weaving in and out and going more than 48 Mph and a few drivers driving exactly the posted 45 Mph. But, most drivers will be driving 48 Mph.

How do you define with specific, precise instructions "driving with the traffic?" Such a statement like “driving with the traffic” can be self-explanatory or obvious to many. But there will be a few people who don’t understand as this conflicts with posted speed limits and their interpretation of the local driving laws.

All drivers (yes, the good ones and the bad ones!) must process these inputs by exercising "fuzzy logic" - receiving a large number of fuzzy inputs, somehow evaluating all the inputs in their human brains and summarizing, weighting and averaging all these inputs to yield an optimum output decision. Think about it…...inputs being evaluated may include several images and considerations such as:

- Any "old clunkers" going real slow.
- Any trucks holding up one of the lanes.
- Side traffic entering from side streets.
- How many cars are in front of you….and where are they?
- How fast are they driving.
- Do the police ever set up radar surveillance on this stretch of road.
- How much leeway do the police allow over the 45 Mph limit.

- What do you see in the rear view mirror?

Examples of Setting Up Fuzzy Sets

In looking at height as an example, below are 5 individuals along with their "crisp" data points, which are exact height measurements. We can define "Tall" as being anything above 5' 10". This leads to two additional sets…one defined with crisp data and the other defined using fuzzy logic. Note, the participation number or percent for any given individual (i.e. Bob having a 0.40 participation number) is determined by the system creator.

Define: Tall > 5 Ft 10 inches

	Description	Height	Crisp Analysis	Fuzzy Set membership
		Ft In	In or out of Set	Between 0 and 1
Jim	"Tall"	6 6	in	0.95
Jon	"Tall"	6 2	in	0.8
Tom	"Tall"	5 11	in	0.6
Bob	"Tall"	5 9	out	0.4
Bill	"Tall"	5 6	out	0.2

A second example provided below targets river lengths.

Define: Long River > 1,000 Meters

	Description	Length	Crisp Analysis	Fuzzy Set membership
		Meters	In or out of Set	Between 0 and 1
Nile	"Long River"	4,180	in	1
Mississippi	"Long River"	2,348	in	0.82
Danube	"Long River"	1,766	in	0.75
Rhine	"Long River"	820	out	0.4
Hudson	"Long River"	306	out	0.15

Applying the idea of fuzzy sets, a marketing person might be very interested in the following example. You can see there may be some gray areas when a perspective customer might not fit into any "hard and crisp" rules applied to the data.

Fact:	**Question:**
Jill Plays Tennis, twice per year	Is Jill a tennis player?
Marie lives half yr in France; half in Brazil	Is Marie a resident of France?
"Heap of Sand" remove a grain at a time…….	When does the "heap" not be a "heap"? Or Pile?

By having fuzzy sets, a marketing program might target both main bodies of potential customers along with marginally potential customers.

Examples of Setting Up Fuzzy Rules to be Applied to Fuzzy Sets.

Re-visit the interaction of automobiles on roads. This includes both driver-controlled and driverless cars. Some of the fuzzy rules and thus the controlling language might be given as follows:

- Rules for controlling a car:
  - Variables are *distance* to the car in front and how fast it is changing, *delta*, and *acceleration* to apply
  - Sets are:
    - Very small, small, perfect, big, very big - for distance
    - Shrinking fast, shrinking, stable, growing, growing fast - for delta
    - Brake hard, slow down, none, speed up, floor it - for acceleration
  - Rules for every combination of distance and delta sets, defining an acceleration set

- Relevant rules are:
  - If distance is small and delta is growing, maintain speed
  - If distance is small and delta is stable, slow down
  - If distance is perfect and delta is growing, speed up
  - If distance is perfect and delta is stable, maintain speed

The example above is only a partial list of rules but illustrates the kind of thinking our brain does when we drive a car and monitor other cars around us. We have a 'feel' for our distance to another car….but that data is not crisp. We may have a 'feel' for our acceleration or even relative acceleration between cars…again, not crisp data. Last, we have a 'feel' for the difference between the two cars without knowing exactly how fast we are traveling nor exact distances or road conditions (determining braking distances). On the other hand, a driver-less car has these rules and evaluations in its program along with many more caveats (or, at least we hope!).

Applying Fuzzy Operators in Real World Scenarios

Fuzzy logic has been used in application areas such as project management, product pricing models, sales forecasting, criminal identification, process control and signal processing. A small sample of the application of fuzzy controls in the real world are:

General Fuzzified Applications

- Quality Assurance
- Error Diagnostics
- Control Theory
- Pattern Recognition
- Elevators
- Vacuum Cleaners
- Hair Dryers
- Air Control in Soft Drink Production
- Noise Detection on Compact Disks
- Cranes
- Electric Razors
- Camcorders
- Television Sets
- Showers

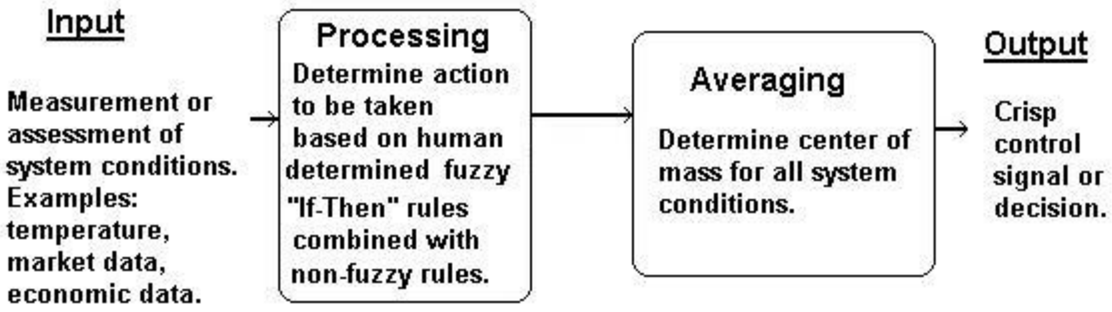
All of these applications required fuzzy logic analysis leading to fuzzy decisions and crisp actions and can be naively described as follows:

1. Receiving of a single or a large number of measurement(s) or other assessment of conditions existing in some system we wish to analyze or control.

2. Processing all these inputs according to human based, fuzzy "If-Then" rules, which can be expressed in plain language words. (Warning here: if all data points or outcomes are not covered (say data points going to plus or minus infinity) in these rules, the system or process can quickly become unstable).

3. Averaging and weighting the resulting outputs from all the individual rules into one single output decision or signal which decides what to do or tells a controlled system what to do. The output signal eventually arrived at is a precise appearing, defuzzified, "crisp" value.

Please see the following Fuzzy Logic Control/Analysis Method diagram:



The Fuzzy Logic Control-Analysis Method

Other areas to explore outside the scope of this presentation might include:

Fuzzy Mathematics

- Fuzzy Numbers – almost 5, or more than 50
- Fuzzy Geometry – Almost Straight Lines
- Fuzzy Algebra – Not quite a parabola
- Fuzzy Calculus
- Fuzzy Graphs – based on fuzzy points

Summary

The intent of this presentation is to introduce the “fuzzy” concept so that engineers and managers can have a little comfort on the subject. The major result in applying fuzzy logic to control systems is that this approach provides smoother transitions. There are no sharp boundaries in the application stage even though a fuzzy might have such boundaries. That is to say, if data points are increasing and nearing an end point of one fuzzy set, that same data point can be a member of another fuzzy set near that fuzzy set’s midpoint. It might be that this second fuzzy set that now controls the outcome of the system.

The idea of fuzzy sets and analysis is not new as it was developed in the 1960’s. Since that time, many applications have been commercialized in the control and systems arenas. Fuzzy logic allows the ability to utilize crisp data in such a way that data points can be associated with different fuzzy sets. Then, these sets themselves can be analyzed to create some outcome….with that outcome being a crisp decision.

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“Fuzzy Logic: An Introduction”

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