Fuzzy Logic Systems Design for Engineering and Applications

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Abstract - **Fuzzy logic system design has rapidly become one of the most successful of today's technologies for developing sophisticated logically designs system. Fuzzy logic addresses such applications perfectly as it resembles human decision making with an ability to generate precise solutions from certain or approximate information. Complex fuzzy logic is a generalization of traditional fuzzy logic, based on complex fuzzy sets. In complex fuzzy logic, inference rules are constructed and "fired" in a manner that closely parallels traditional fuzzy logic. The range of these membership functions is extended from the traditional fuzzy range of [0,1] to the unit circle in the complex plane, thus providing a method for describing membership in a set in terms of a complex number. Several mathematical properties of complex fuzzy sets, which serve as a basis for the derivation of complex fuzzy logic, are reviewed in this paper. These properties include basic set theoretic operations on complex fuzzy sets namely complex fuzzy union and intersection, complex fuzzy relations and their composition vector aggregation.**

A large numbers of fuzzy control applications with the physical systems require a real-time operation to interface high speed constraints; higher density programmable logic devices such as field programmable gate array can be used to integrate large amounts of logic in a single IC. The fuzzy design starts with an overview of engineering in order to get an idea about design architecture, and followed by an explanation on the hardware implementation with both type analogue and digital implementation, also provided in this system design application.

Index Terms-- **Traditional fuzzy logic, Logic, hardware implementation, Digital technique, Analog technique.**

I. INTRODUCTION

Many decision-making and problem-solving tasks are too complex to be understood quantitatively, however, people succeed by using knowledge that is imprecise rather than precise. Fuzzy set theory, originally introduced by Lotfi Zadeh in the 1960's, resembles human reasoning in its use of approximate information and uncertainty to generate decisions. It was specifically designed to mathematically represent uncertainty and vagueness and provide formalized tools for dealing with the imprecision intrinsic to many problems. By contrast, traditional computing demands precision down to each bit. Since knowledge can be expressed in a more natural by using fuzzy sets, many engineering and decision problems can be greatly simplified. Most of the fuzzy logic applications with the physical systems require a real-time operation to interface high speed constraints the simple and usual way to implement these systems is to realize it as a software program on general purpose computers, these ways cannot be considered as a suitable design solution. Higher density programmable logic device such as Fuzzy can be used to integrate large amounts of logic in a single IC.

For these systems, are more sufficient than the simple way because they can cover a much wider range of operating conditions. Semi-custom and full-custom application specific integrated circuit (ASIC) devices are also used for this purpose but provide additional flexibility: they can be used with tighter time-to-market schedules. Places fixed logic cells on the wafer, and the designer constructs more. Complex functions from these cells [11]. The term field Programmable highlights the customizing of the IC by the user, rather than by the foundry manufacturing the several researchers discussed the design of hardware systems. Numbers of these works were specialized in control application, and were aim to get better control responses. In an Fuzzy logic blocks are implemented using multiple level low fan in gates, which gives it a more compact design compared to an implementation with two-level AND-OR logic. Fuzzy provides its user a way to configure: The intersection between the logic blocks and the function of each logic block. Logic block of

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a system can be configured in such a way that it can provide functionality as simple as that of transistor or as complex as that of a microprocessor. . Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false.

II. HARDWARE IMPLEMENTATION TECHNIQUES

The techniques used for hardware implementation include:

A. Analog Techniques

The variables in fuzzy systems are analog by nature. Thus, analog implementation eliminates the need for analog-to-digital and digital-to-analog conversions. The fuzzy systems also require massive parallelism, making analog circuits particularly suited for their implementation. Furthermore, the physical characteristics of transistors can be utilized in realizing the nonlinear functions required, whether it is a fuzzy operation, or a membership function. Analog implementations, however, have typically very restricted possibilities for programmability. Analog implementation techniques include voltage mode and current mode realizations, in addition to mixed mode (current and voltage) realizations.

B. Digital Techniques

Although fuzzy chips may have limited input/output capabilities, they have particularly useful applications in real-time control systems. Analog fuzzy values must be converted to binary digital signals. Analog-to-digital conversion can lead to quantization errors in both input signals and membership values. Thus, decline in the fuzzy processing may occur if an insufficient number of bits are used to represent the analog signals. On the other hand, using a large number of bits can slow down the process. This is the trade-off between precision and speed. Fuzzy dedicated circuits are characterized by:

- The number of inputs and outputs.
- The number and shapes of membership functions.
- Inference techniques including operators, con sequences and Size of the premises.
- Defuzzification method.
- The number of fuzzy logic inferences per second.
- Physical size.
- Power consumption.
- Software available to support the design.

III. FUZZY LINGUISTIC VARIABLES CRISP SETS

While variables in mathematics usually take numerical values, in fuzzy logic applications, the non-numeric linguistic variables are often used to facilitate the expression of rules and facts. A linguistic variable such as age may have a value such as young or its antonym old.. In classical mathematics we are familiar with what we call crisp sets. For example, the possible inter ferometric coherence g values are the set X of all real numbers between 0 and 1. From this set X a subset A can be defined, (e.g. all values 0 _to_ 1). The reasoning in fuzzy logic is similar to human reasoning. It allows for approximate values and inferences as well as incomplete or ambiguous data (fuzzy data) as opposed to only relying on crisp data (binary yes/no choices). Fuzzy logic is able to process incomplete data and provide approximate solutions to problems other methods find difficult to solve. Terminology used in fuzzy logic not used in other methods is: very high, increasing, somewhat decreased, reasonable.The characteristic function of A, (i.e. this function assigns a number 1 or 0 to each element in X, depending on whether the element is in the subset A or not) logical operations. The elements which have been assigned the number 1 can be interpreted as the elements that are in the set A and the element which have assigned the number 0 as the elements that are not in the set of logic design.

IV. THE ESSENTIAL CHARACTERISTIC OF FUZZY LOGICSYSTEM DESIGN

In fuzzy logic, exact reasoning is viewed as a limiting case of approximate reasoning. In fuzzy logic everything is a matter of degree. Any logical system can be fuzzified .In fuzzy logic, knowledge is interpreted as a collection of elastic or, equivalently fuzzy constraint on a collection of variables Inference is viewed as a process of propagation of elastic constraints. The third statement hence, defines Boolean logic as a subset of Fuzzy logic.

A. Fuzzy Patches Design

In a fuzzy system this simply means that all our rules can be seen as patches and the input and output of the machine can be associated together using these patches. Graphically, if the rule patches shrink, our fuzzy subset triangle gets narrower. Simplest method Yes, because even novices can build control systems that beat the best math models of control theory. Naturally it is math-free system.

B. Fuzzy Control Design

Fuzzy logics control design in which directly uses fuzzy rules is the most important application in fuzzy theory. Using a procedure originated by Ebrahimi Madman in the late 70s, three steps are taken to create a fuzzy controlled machine Fuzzification (Using membership functions to graphically describe a situation) Rule evaluation n(Application of fuzzy rules Defuzzification (Obtaining the crisp or actual results).

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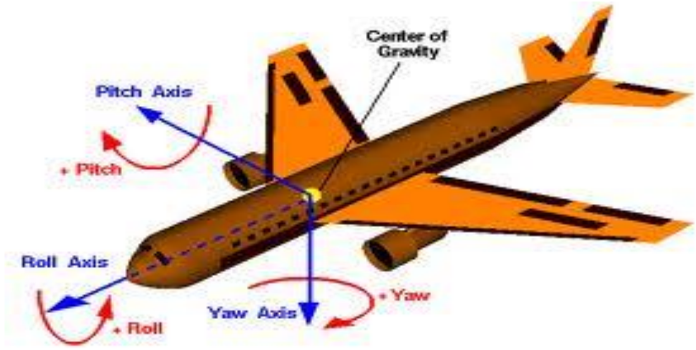

Fig. 1 Fuzzy based approach to design of Flight Control

As a simple example on how fuzzy controls are constructed, devices consider the following classic situation: the inverted pendulum. Here, the problem is to balance a pole on a mobile platform that can move in only two directions, to the left or to the right. The angle between the platform and the pendulum and the angular velocity of this angle are chosen as the inputs of the system. The speed of the platform hence, is chosen as the corresponding output .T here are various points are given.

- First of all, the different levels of output (high speed, low speed etc.) of the platform are defined by specifying the Membership functions for the fuzzy sets. The graph of the Function is shown below Similar, the different and between the platform and the pendulum and the angular Velocities of specific angles are also defined.
- For simplicity, it is assumed that all membership Functions are speeded equally. Hence, this explains Why No actual scale is included in the graphs.
- The next step is to define the fuzzy rules. The fuzzy rules are mealy a series of if-then statements as mentioned above.

These statements are usually derived by an expert to achieve optimum results. Some examples of these rules Based system as following:

Rule 1*:* If angle is zero and angular velocity is zero then speed is also zero.

Rule 2*:* If angle is zero and angular velocity is low then the Speed shall be low. The full set of rules is the dashes Are for conditions, which have no rules associated with them.

V. FUZZY LOGIC SYSTEM DESIGN SETS

Fuzzy Set Theory was formalized by Professor Lofty Zadeh at the University of California in 1965. What Zadeh proposed is very much a paradigm shift that first gained acceptance in the Far East and its successful application has ensured its adoption around the world. A paradigm is a set of rules and regulations which defines boundaries and tells us what to do to be successful in solving problems within these boundaries.

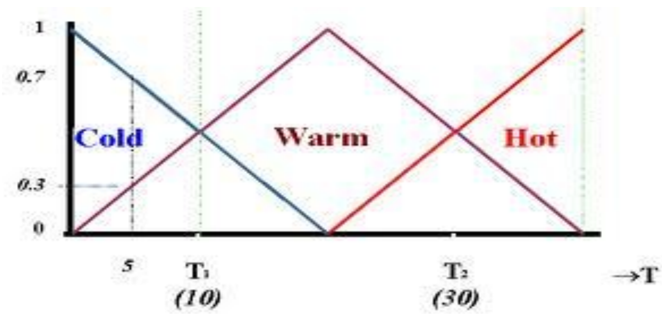

Fig. 2 Fuzzy logic based define temperature of a room

For example, Fig 1 below illustrates bivalent sets to characterize the temperature of a room. The most obvious limiting feature of bivalent sets that can be seen clearly from the diagram is that they are mutually exclusive it is not possible to have membership of more than one set opinion would widely vary as to whether 50 degrees Fahrenheit is 'cold' or 'cool' hence the expert knowledge we need to define our system is mathematically at odds with the humanistic world).

Clearly, it is not accurate to define a transition from a quantity such as 'warm' to 'hot' by the application of one degree Fahrenheit of heat. In the real world a smooth (unnoticeable) drift from warm to hot would occur. This natural phenomenon can be described more accurately by Fuzzy Set according to fuzzy logic system design theory say that shows how fuzzy sets quantifying the same information can describe this is nature to drift on the temperatures of the room set according to voltage possible.

VI. FUZZY LOGIC OPERATIONS

The fuzzy logic system design techniques are given below:

A. Union operation

The membership function of the Union of two fuzzy sets A and B with membership functions and respectively is defined as the maximum of the two individual membership functions The Union operation in Fuzzy set theory is the equivalent of the OR operation in Boolean algebra in logic design circuits.

B. Intersection operation

The membership function of the Union of two fuzzy sets A and B with membership functions and respectively is defined as the maximum of the two individual membership functions The Union operation in Fuzzy set theory is the equivalent of the AND operation in Boolean algebra in logic design circuits.

C. Complement operation

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The membership function of the Complement of a Fuzzy set A with membership function is defined as the following rules which are common in classical set theory also apply to Fuzzy set theory.

Fuzzy Logic has been found to be very suitable for embedded control applications. Several manufacturers in the automotive industry are using fuzzy technology to improve quality and reduce development time. In aerospace, fuzzy enables very complex real time problems to be tackled using a simple approach. In consumer electronics, fuzzy improves time to market and helps reduce costs. In manufacturing, fuzzy is proven to be invaluable in increasing equipment efficiency and diagnosingmal functions. In fuzzy logic everything is a matter of degree. Any logical system can be fuzzified in fuzzy logic, knowledge is interpreted as a collection of elastic or, equivalently, fuzzy constraint on a collection of variables Inference is viewed as a process of propagation of elastic constraints.

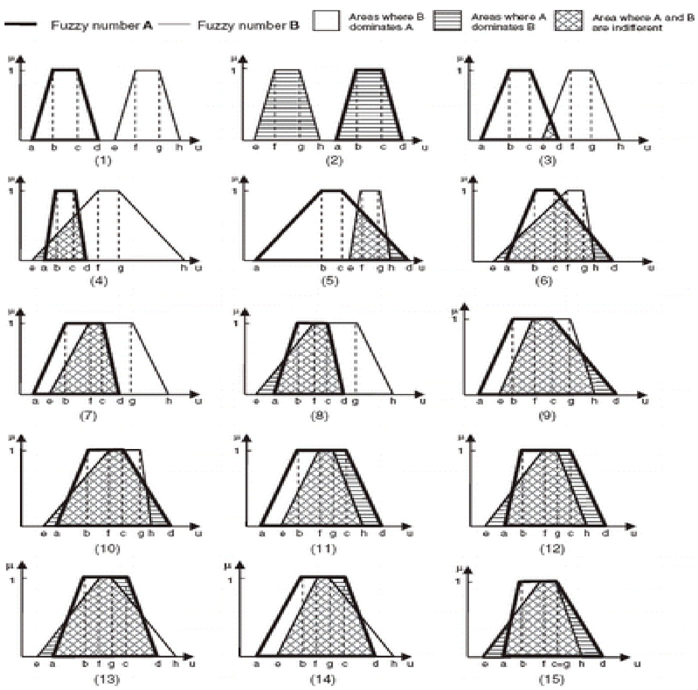

Fig. 3 Fuzzy logic given operations comparison

VII. TIME DEPENDENT FUZZY LOGIC

The Time Dependent Fuzzy Logics system designs are related to two types of categorized based on requirements.

A. Crisp

Traditional combinatorial logic is a static logic. It provides a logic output 1 or 0 based on the binary values at the inputs. Sequential logic takes combinatorial logic a step further; it considers events or states in sequential order. It is a process/state-based logic that, based on current states and input/output parameters, determines the next state. This may be encapsulated in an if Â .then, else statement: if {this happens}, then {do this}, else {do that}. The next stat is merely the next Estela of a process that takes place at a later, unspecified, time. The state diagram in figure (a) substantiates exactly this point: the next state {A ,B or C} in the state diagram depends on the current state{ A ,B, or C} and input {1 pr 0}, whereby the dimension of time is not significant nor explicitly indicated.

For instance, state A will change to state B only when the input will be 1; when the input will become 1, however, is not known. Combinatorial or sequential logic does not address many knowledge intensive and real-time processes where temporal reasoning plays an important role. The logic that extends the traditional logic and predicate calculus to include the notion oftime is called temporal logic. However, combinatorial, sequential, and temporal logics are crisp and the parameter and variable values true/false, exactly binary values (1 or 0).

B. Fuzzy

Fuzzy logics may be considered a generalized combinatorial or sequential logic; however, the passage of time is not necessarily of the essence. In fuzzy control an if Â then, else approach is also followed, where again the passage of time is not of the essence. As with combinatorial and sequential processes. There are real-time fuzzy processes where temporal reasoning is important. However, existing fuzzy control approaches are not result related, they are algorithmically over simple, and they do not reflect real-time evaluation of the control objectives. To overcome this difficulty, different approaches have been proposed but again time is not explicit in these approaches.

VIII. FUZZY LOGIC EXAMPLE

Fuzzy Logic simplifies design complexity Fuzzy logic lets you describe complex systems using your knowledge and experience in simple English-like rules. It does not require any system modeling or complex math equations governing the relationship between inputs and outputs.. It typically takes only a few rules to describe systems that may require several of lines of conventional software. As a result, Fuzzy Logic significantly simplifies design complexity. Fuzzy Logic improves time to market Commercial applications in embedded control require a significant development effort a majority of which is spent on the software portion of the project. As we explained above, a fuzzy set theory defines fuzzy operators on fuzzy sets. The problem in applying this is that the appropriate fuzzy operator may not be known. For this reason, fuzzy logic usually uses IF-THEN rules, or constructs that are equivalent, such as fuzzy associative matrices. Rules are usually expressed in the form: IF *variable* IS *property* THEN

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action .For example, a simple temperature regulator that uses a fan might look like this:

IF temperature IS very cold THEN stop fan
IF temperature IS cold THEN turn down fan
IF temperature IS normal THEN maintain level
IF temperature IS hot THEN speed up fan

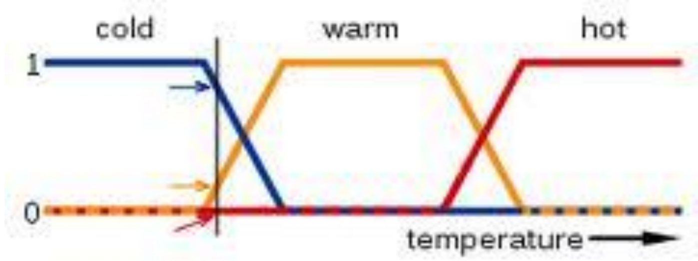

Fig. 4 Fuzzy logic usually IF-THEN rules

There is no "ELSE" – all of the rules are evaluated, because the temperature might be "cold" and "normal" at the same time to different degrees. The AND, OR, and NOT operators of Boolean logic exist in fuzzy logic, usually defined as the minimum, maximum, and complement; when they are defined this way, they are called the *Zadeh operators*. So for the fuzzy variables x and y:

NOT x = (1 - truth(x))
x AND y = minimum(truth(x), truth(y))
x OR y = maximum(truth(x), truth(y))

There are also other operators, more linguistic in nature, called *hedges* that can be applied. These are generally adverbs such as "very", or "somewhat", which modify the meaning of a set using a mathematical formula.

IX. HOW DOES FUZZY LOGIC WORK

In order to illustrate some basic concepts in Fuzzy Logic, consider a simplified example of a thermostat controlling a heater fan .The room temperature detected through a sensor is input to a controller which outputs a control force to adjust the heater fan speed. A conventional thermostat works like an on-off switch if we set it at 78oF then the heater is activated only when the temperature falls below 75oF. When it reaches 81oF the heater is turned off. As a result the desired room temperature is either too warm or too hot.

A fuzzy thermostat works in shades of gray where the temperature is treated as a series of overlapping ranges. For example, 78oF is 60% warm and 20% hot. The controller is programmed with simple if-then rules that tell the heater fan how fast to run. As a result, when the temperature changes the fan speed will continuously adjust to keep the temperature at the desired level. Our first step in designing such a fuzzy controller is to characterize the range of values for the input and output variables of the controller. Then we assign labels such as cool for the temperature and high for the fan speed, and we write a set of simple English-like rules to control the system. Inside the controller all temperature regulating actions will be based on how the current room temperature falls into these ranges and the rules describing the system behavior. The controller's output will vary continuously to adjustment of the fan speed.

Here the linguistic variables cool; warm, high, etc. are labels which refer to the set of overlapping values shown in figure 2. These triangular shaped values are called membership functions. A fuzzy controller works similar to a conventional system: it accepts an input value, performs some calculations, and generates an output value. This process is called the Fuzzy Inference Fuzzification where a crisp input is translated into a fuzzy value, Rule Evaluation, where the fuzzy output truth values are computed, and © Defuzzification where the fuzzy output is translated to a crisp value. During the Fuzzification step the crisp temperature value of 78oF is input and translated into fuzzy truth values. For this example, 78oF is fuzzified into warm with truth value 0.6 (or 60%) and hot with truth value 0.2 (or 20%).

During the rule evaluation step the entire set of rules is evaluated and some rules may fire up. For 78oF only the last two of the four rules will fire. Specifically, using rule three the fan speed will be low with degree of truth 0.6. Similarly, using rule for the fan speed will be zero with degree of truth 0.2. During the Defuzzification step the 60% low and 20% zero labels are combined using a calculation method called the Center of Gravity (COG) in order to produce the crisp output value of 13.5 RPM for the fan speed.

X. WHY USE FUZZY LOGIC

An Alternative Design Methodology Which Is Simpler, Faster fuzzy Logic reduces the design development cycle. Fuzzy Logic simplifies design complexity Fuzzy Logic improves time to market A Better Alternative Solution To Non-Linear Control Fuzzy Logic improves control performance Fuzzy simplifies implementation Fuzzy Logic reduces hardware costs Fuzzy Logic is a paradigm for an alternative design methodology which can be applied in developing both linear and non-linear systems for embedded control. By using fuzzy logic, designers can realize lower development costs, superior features, and better end product performance. Furthermore, products can be brought to market faster and more cost-effectively. An Alternative Design Methodology Which Is Simpler, And Faster In order to appreciate why a fuzzy based design

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methodology is very attractive in embedded control applications let us examine a typical design flow.

Using the conventional approach our first step is to understand the physical system and its control requirements. Based on this understanding, our second step is to develop a model which includes the plant, sensors and actuators. The third step is to use linear control theory in order to determine a simplified version of the controller, such as the parameters of a PID controller. The fourth step is to develop an algorithm for the simplified controller. The last step is to simulate the design including the effects of non-linearity, noise, and parameter variations. If the performance is not satisfactory we need to modify our system modeling, re-design the controller, re-write the algorithm and re-try.

A. Fuzzy logic system behavior

With Fuzzy Logic the first step is to understand and characterize the system behavior by using our knowledge and experience.

B. Fuzzy logic control algorithm

The second step is to directly design the control algorithm using fuzzy rules, which describe the principles of the controller's regulation in terms of the relationship between its inputs and outputs.

C. Fuzzy logic simulates and design

The third step is to simulate and debug the design. If the performance is not satisfactory we only need to modify some fuzzy rules and re-try. Although the two design methodologies are similar, the fuzzy-based methodology substantially simplifies the design loop.

D. Fuzzy logic methodology

The last step is to results in some significant benefits, such as reduced development time, simpler design and faster time to market. Fuzzy Logic reduces the design development cycle with a fuzzy logic design methodology some time consuming steps are eliminated. Moreover, during the debugging and tuning cycle you can change your system by simply modifying rules, instead of redesigning the controller. Based design methodology addresses both issues very effectively.

Moreover, due to its simplicity the description of a fuzzy controller not only is transportable across design teams, but also provides a superior media to preserve, maintain, and upgrade intellectual property. As a result, Fuzzy Logic can dramatically improve time to market. A Better Alternative Solution To Non-Linear Control Most real life physical systems are actually non-linear systems. Conventional design approaches use different approximation methods to handle non-linearity. Some typical choices are, linear, piecewise linear, and lookup table approximations to trade off factors of complexity, cost, and however it tends to limit control performance and may be costly to implement in certain applications. A piecewise linear technique works better, although it is tedious to implement because it often requires the design of several linear controllers. Fuzzy logic provides an alternative solution to non-linear control because it is closer to the real world. Non-linearity is handled by rules, membership functions, and the inference process which results in improved performance, simpler implementation, Fuzzy Logic improves control performance
In many applications Fuzzy Logic can result in better control performance than linear, piecewise linear, or lookup table techniques. For instance, a typical problem associated with traditional techniques is trading-off the controller's response time versus overshoot. For the simple one-input temperature controller the first linear approximation for the desired curve generates a slow output response with no overshoot, which implies that the room would be too cold for a while. The second linear approximation results in faster response with an overshoot and subsequent fluctuations, which implies that the temperature will be uncomfortable for a period of time.
With fuzzy logic we can use rules and membership functions to approximate any continuous function to any degree of precision. Figure 6 illustrates how we can approximate the desired control curve for our temperature controller using four points (or four rules). We can also add more rules to increase the accuracy of the approximation (similar to a Fourier transform), which yields an improved control performance. Rules are much simpler to implement and much easier to debug and tune than piecewise Rules are not like a lookup table because the fuzzy arithmetic interpolates the shape of the non-linear function. The combined memory required for the labels and fuzzy inference is substantially less than a lookup table, especially for multiple input systems. As a result, processing speed can be improved as well. Another example of robust control that can be achieved with Fuzzy Logic is the classical problem of the inverted pendulum. A conventional controller for the pendulum depends on system parameters such as length, weight, and mass. If the parameters change, then we need to re-design our controller. With fuzzy control this is not necessary because a fuzzy system is robust. Aptronix has demonstrated an actual device where we can vary the weight or length of the pendulum and the system is still stable using the original set of rules.
By using a more natural rule-based approach which is closer to the real world, Fuzzy control can offer a superior performance and a better trade-off between system robustness and sensitivity, which results into handling non-linear control better than traditional methods.

XI. CONCLUSION

Fuzzy logic is a powerful problem-solving methodology with a myriad of applications in embedded control and information processing. Fuzzy provides a remarkably simple way to draw

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definite conclusions from vague, ambiguous or imprecise information. In a sense, fuzzy logic resembles human decision making with its ability to work from approximate data and find precise. Unlike classical logic which requires a deep understanding of a system, exact equations, and precise numeric values, Fuzzy logic incorporates an alternative way of thinking, which allows modeling complex systems using a higher level of abstraction originating from our knowledge and experience. Fuzzy Logic allows expressing this knowledge with subjective concepts such as very hot, bright red, and a long time which is Used. Fuzzy Logic has been gaining increasing acceptance during the past few years. There are over two thousand commercially available products using Fuzzy Logic, ranging from washing machines to high speed trains. Nearly every application can potentially realize some of the benefits of Fuzzy Logic, such as performance, simplicity, lower cost, and productivity. Fuzzy Logic has been found to be very suitable for embedded control applications. Several manufacturers in the automotive industry are using fuzzy technology to improve quality and reduce development time. In aerospace, fuzzy enables very complex real time problems to be tackled using a simple approach. In consumer electronics, fuzzy improves time to market and helps reduce costs.

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