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A Review on Fuzzy-Logic Method to Control Robotic Manipulator Systems

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Abstract

The application of the concepts of fuzzy set theory in structural control has recently attracted increasing interests. Fuzzy controllers afford a simple and robust framework for specifying nonlinear control laws which accommodate uncertainty and imprecision. The current research reviews fuzzy logic applications in controlling robotic manipulators. An introduction to fuzzy logic method is presented, then a short review is provided on literature and three applications of fuzzy logic are considered as: mobile robot, flexible single link and two links manipulators.

Keyword and Phrases
Fuzzy-Logic Method, Control, Mobile Robot, Flexible Manipulator.

1. Introduction

Fuzzy Logic (FL) was initiated in 1965 [1-3], by A.L. Zadeh, professor for computer science at the University of California in Berkeley. Basically, FL is a multivalued logic which allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low, etc. Notions like rather tall or very fast can be formulated mathematically and processed by computers, in order to apply a more human-like way of thinking in the programming of computers [4]. Fuzzy systems are an alternative to traditional notions of set membership and logic that has its origins in ancient Greek philosophy. The precision of mathematics owes its success in large part to the efforts of Aristotle and the philosophers who preceded him. In their efforts to devise a concise theory of logic, and later mathematics, the so-called “Laws of Thought” were posited [5]. One of them, the ”Law of the Excluded Middle,” states that every proposition must either be true or false. Even when Parmenides proposed the first version of this law (around 400 B.C.) there were strong and immediate objections: for example, Heraclitus proposed that things could be simultaneously true and not true. It was Plato who laid the foundation for what would become FL, indicating that there was a third region (beyond True and False) where these opposites "tumbled about". Other, more modern philosophers echoed his sentiments, notably Hegel, Marx, and Engels. But it was Lukasiewicz who first proposed a systematic alternative to the bi–valued logic of Aristotle [6]. Even in the present time some Greeks are still outstanding examples for fussiness and fuzziness. Fuzzy Logic has emerged as a profitable tool for controlling and steering of systems and complex industrial processes, as well as household and entertainment electronics, as well as other expert systems and applications like the classification of SAR data.

This paper provides an outline of FL method specially its process steps including preprocess, fuzzification, rule base, inference fuzzy and defuzzification. Then, the applications of FL approach in mobile robot, single link and two links flexible manipulators are considered as a brief literature survey.

2. Fuzzy Method

Fuzzy logic deals with uncertainty in engineering by attaching degrees of certainty to the answer to a logical question. Why should this be useful ? The answer is commercial and practical. Commercially FL has been used with great success to control machines and consumer products. In the right applications FL systems are simple to design, and can be understood and implemented by non-specialists in control theory. In most cases some one with an intermediate technical background can design specialists in control theory. In most cases someone with an intermediate technical background can design engineers also use it in applications where the on-board computing is very limited and adequate control is enough [7]. Fuzzy logic is not the answer to all technical problems, but for control problems where simplicity and speed of implementation is important then FL is a strong candidate.

Generally, the fuzzy controller consists of four components. First, the rule base which holds the knowledge of how best to control the system. Second, the inference mechanism which decides on the relevant control rules for the current time and, then, chooses the best input to the plant. Third, the fuzzification interface which simply modifies the inputs for interpreting and comparing with the rules in the rule base. Forth, the defuzzification interface which converts the inference mechanism conclusions into the inputs to the plant. The schematic closed-loop fuzzy controller block diagram is shown in Fig. 1.

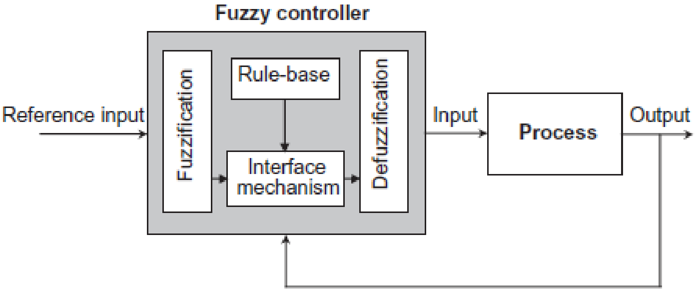


Fig. 1 Fuzzy controller scheme

2.1 Define of Membership Function

A Fuzzy set F in a space of points S = {s} is a set of elements with a varying grade of membership and is characterized by a membership function that maps each element of S to a real number in the interval [0 1]. The value of for any given s indicates the degree of s in F or the degree an s belongs to. Thus the membership function is defined as:

$$\mu_F(x) = \begin{cases} 1 & x \in F \\ 0 & x \notin F \end{cases} \tag{2.1}$$

where the following relation can be written:

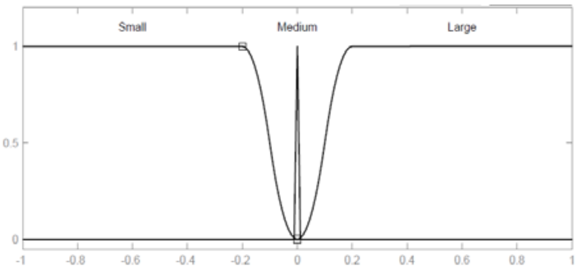
$$F = \int_S \mu_F(x)/x \tag{2.2}$$

and for a discredited space, (2.2) can be rewritten as:

$$F = \sum_S \mu_F(x)/x \tag{2.3}$$

2.2 Fuzification of Input

Fuzzification of inputs is necessarily determining the degree to which they belong to each of the appropriate fuzzy sets via membership functions. Some of membership functions can be shown in Fig. 2.



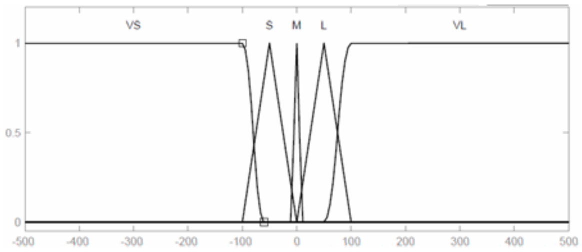


Fig. 2 Membership functions

2.3 Define of Rules

The next step is laying down certain rules, which relate the inputs to an output parallel nature of the rules is one of the most important aspects of FL systems. The transition from a region where the system's behavior is dominated by one rule to a region where another dominates it is smooth, avoiding sharp switching between modes based on breakpoints. A single fuzzy if-then rule assumes the form (Fig. 3).

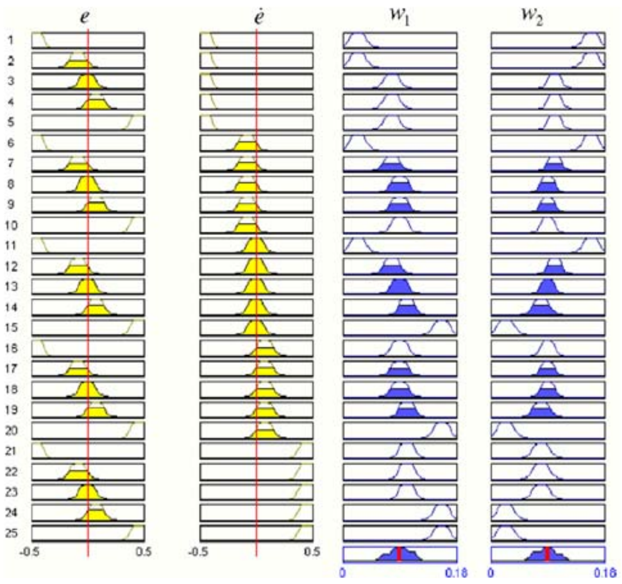


Fig. 3 Fuzzy rules

2.4 Fuzzy Interface

Since decisions are based on the testing of all of the rules, the rules must be combined in some manner in order to make a decision. Aggregation is the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set The output of the aggregation process is one fuzzy set for each output variable All the rules are evaluated together and the output of each rule is combined, or aggregated, into a single fuzzy set whose membership function assigns a weighting for every output value.

2.4 Define of Rules

The defuzzification process transforms the fuzzy set (the aggregate output fuzzy set into a single number. The aggregate of a fuzzy set encompasses a range of output values, and so must be defuzzified in order to resolve a single output value from the set. This defuzzification method could employ methods like- centric, bisector, middle of maximum (the average of the maximum value of the output set), largest of maximum, smallest of maximum and other such criteria.

3. The Application of Fuzzy-Logic in Robot Manipulators

For many years, classical control engineers began their work with a mathematical model, and did not acquire further knowledge of the system. Today, control engineers use all of the above sources of information. Although a relatively new concept, FL is being used in many engineering applications because it is considered by designers to be the simplest solution available for the specific problem. Another benefit of fuzzy controllers is they are basically non-linear, and effective enough to provide the desired non-linear control actions by carefully adjusting their parameters. Typically, the accurate mathematical models of real physical mechanisms or machines are not available or extremely hard to formulate. This is one of the most basic problems which designers are encountered with in the development of practical control systems. For these problems, fuzzy control offers a superior solution by incorporating linguistic information from human experts. But, the primary reason for investigators being interested in fuzzy control is that it can be used to describe human being’s vague thinking in a mathematically strict sense. In fact, fuzzy control offers a formal method to represent, manipulate, and implement a human’s heuristic knowledge on how to control a system.

3.1 Mobile Robot

Mobile manipulators are combined systems consisting of a robotic manipulator mounted on a mobile platform. These systems are able to accomplish complicated tasks in large workspaces. They have a compact structure and high maneuverability and are cost effective [8]-[11]. Such systems are more difficult to approximate and to control than first-order processes, and are treated by some researchers [12]-[14]. What gives FL advantages over more traditional solutions for control of mobile robots is that it allows computers to reason more like humans, responding effectively to complex inputs to deal with linguistic notions such as 'too hot', 'too cold' or 'just right'. Such systems can be easily upgraded by adding new rules to improve performance or add new features. In many cases, fuzzy control can be used to improve existing traditional control systems in mobile robots by adding an extra layer of intelligence to the current control method. In many cases, the mathematical model of the system to be controlled may not exist, or may be too "expensive" in terms of computer processing power and memory, and a system based on empirical rules may be more effective. In 15], a theoretical model of a fuzzy based reactive controller for a non-holonomic mobile robot is developed. Moreover, a heuristic fuzzy-neuro network is presented for pattern-mapping between sensor data and motion commands to the mobile robot. In this work, combining some useful heuristic rules with the fuzzy resulted in the desired mapping between perception and motion, and provides much faster response to unexpected events [16]. Yang et al. 167] proposed an augmentation to previous applications of FL to 2D robot motion planning. Peri and Simon 18], presented a FL controller to control the motion of differential drive mobile robots. Then, they carried out simulations on a non-holonomic mobile robot to test the performance of the proposed fuzzy controller. A reinforcement ant optimized fuzzy method for wall-following control of a wheeled mobile robot is proposed in [19]. The main feature of their method is that a priori assignment of fuzzy rules is not necessary, and an online aligned fuzzy-logic method is proposed to generate rules automatically. Cheng et al [20] presented a hierarchical fuzzy based controller for backward tracking control of a mobile robot with one trailer. Wen et al [21] used Elman fuzzy adaptive control for obstacle avoidance of mobile robots. They used an Elman fuzzy adaptive controller to adjust the exact distance between the robot and the obstacles. Furthermore, a new FL method is developed for path control of mobile robot by means of a ceiling-mounted camera which observes the robot’s work space [22].

3.1 Single-link flexible manipulator

A flexile link arm is a distributed parameter system of infinite order, but must be approximated by a lower-order model and controlled by a finite-order controller due to onboard computer limitations and sensor inaccuracy [23]. The so-called “control spillover” and “observation spillover” effects then occur, which under certain conditions can lead to instability [24].

Literature on the flexile arm is surveyed in this work shows that there are serious limitations on the effectiveness of standard rigid-arm control schemes. Several control schemes have recently been proposed for flexible robot arms a controller that is based upon a reduced-order model is proposed in to maintain reasonable computational loading. Over the recent years, singular per duration theory has been demonstrated to provide a convenient means “reduced-order modeling”. The dynamics of singularly perturbed systems can be ape proximate by the dynamics of the corresponding reduced-order and boundary layer subsystems for sufficiently small values of the singular perturbation parameter. The aim is to simplify the software and hardware implementation of control algorithms while improving their robustness 25]. A composite control approach, based on a two-time scale model of the flexile-link arm has been derived in, and allows a definition of a slow subsystem that corresponds to a rigid body and a fast subsystem that describes the exile motion.

In prior researches, there were two main drawbacks in fuzzy control: the design of fuzzy controllers was usually performed in an ad hoc manner where it was often difficult to choose some of the controller parameters; and the fuzzy controller constructed for the nominal plant might later perform inadequately if significant and unpredictable plant parameter variations occurred. Moudgal et al [26] studied these drawbacks, and developed and implemented a fuzzy model reference learning controller for the flexible robot and illustrated that it can automatically synthesize a rule-base for a fuzzy controller that will achieve improved performance. Moreover, an experimental study on active vibration control of a single-link flexible manipulator using tools of fuzzy logic and neural networks is presented in [27]. The controller is used to dampen the end-point vibration in a single-link flexible manipulator, and developed appropriate FL rules to control of the system. Tokhi and Alam [28]designed a feed-forward command shapers controller with multi-objective genetic optimization for vibration control of a single-link flexible manipulator. Pereira et al [29] proposed a hybrid control strategy for vibration damping and precise tip-positioning of a single-link flexible manipulator. Shi and Zheng [30] used a distributed fuzzy logic controller for a single-link flexible manipulator. The control strategy leads to better controlling-precision, lesser vibration at the tip position and faster response. Furthermore, an adaptive fuzzy output feedback approach is proposed for a single-link robotic manipulator with a non-rigid joint driven by an electrical motor [31]. The controller is designed to compensate for the nonlinear dynamics associated with the mechanical subsystem and the electrical subsystems. Here in, fuzzy logic systems are used to approximate the unknown nonlinearities, an adaptive fuzzy filter observer is designed to estimate the immeasurable states. Furthermore, Amini Khoiy et al. [32] used the fuzzy logic method to control a single link manipulator. The architecture of their proposed method is shown in Fig. 4.

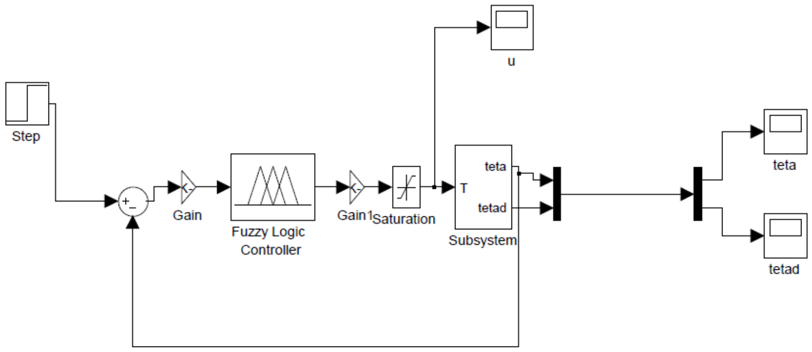


Fig. 4 Fuzzy controller for a single link manipulator [32]

3.3 Two-link Flexible Manipulator

In some control tasks, such as those in robot manipulation, the systems to be controlled have constant or slowly-time varying uncertain parameters constant or slowly-time varying uncertain parameters reduced on-line by an appropriate adaptation or estimation mechanism, it may cause inaccuracy or instability for the control systems. In many other tasks such as those in power systems, the system dynamics may have well known dynamics at the beginning, but experience unpredictable parameter variations as the control operation goes on. Without continuous redesign of the controller, the initially appropriate controller design may not be able to control the changing plant well. The problem of adaptation of dynamical systems having parameter uncertainty has attracted a lot of research efforts in all times. In particular, for nonlinear systems, several approaches have been proposed to deal with this important problem34].

Recently, much attention has been devoted to fuzzy control for robotic manipulators. The latest survey on fuzzy control for robotic manipulators can be found in 35] and references cited therein. Luh 36] combined fuzzy control and variable structure control to construct a controller, where fuzzy system was greatly simplified by using system representative point and its derivative as inputs. Sun et al. [39] designed a control laws consisted of a regular fuzzy controller and a supervisory control term, which ensured stability of closed-loop systems. Yoo and Ham [37] studied adaptive control of robot manipulator using fuzzy compensator. In order to compensate the parametric uncertainties of the system, they used the FL system that has the capability to approximate any nonlinear function over the compact input space. Green et al [38] presented fuzzy and optimal control of a two-link flexible manipulator. Here in, a FL control strategy incorporates two fuzzy controllers substituted for the LQR state-space dynamics equations, and a linear quadratic Gaussian (LQG) strategy controls a two-link flexible robot manipulator tracking a two-dimensional square trajectory. In [39], two fuzzy control schemes for a class of uncertain continuous-time multi-input multi-output nonlinear dynamical systems were derived. Satisfactory performances were achieved by applying them to robotic manipulators [40]. Moreover, Fuzzy terminal sliding mode control of two-link flexible manipulators is presented in [41]. The flexible manipulator system is firstly decomposed into two subsystems by modeling the joint angles and the corrected flexible modes as the slow and fast variables, based on the singular perturbation method and two time-scale decomposition. Then, a nonsingular terminal sliding mode manifold is proposed for the slow subsystem to realize fast convergence and better tracking precision. Meanwhile, a hybrid controller for the slow subsystem is proposed to ensure strong robustness, as well as to weaken chattering phenomenon using fuzzy logic. Alavandara et al [42] presents the social foraging behavior of Escherichia coli bacteria to optimize hybrid Fuzzy Pre-compensated Proportional-Derivative (PD) controller in trajectory control of a two link rigid-flexible manipulator. Zebin and Alam [43] studied dynamic modeling and fuzzy logic control of a two-link flexible manipulator using genetic optimization techniques. Hence dynamic modeling of the constrained two-link flexible manipulator is derived via finite element method, a Genetic Algorithm (GA) based hybrid fuzzy logic control strategy is also developed to reduce the end-point vibration of a flexible manipulator without sacrificing its speed of response. Also, they employed fuzzy logic and genetic optimization techniques for control of a two-link flexible manipulator [44]. Piltan et al [45] proposed a fuzzy based hybrid control strategy for position control of a two-link manipulator. Furthermore, a novel hybrid control scheme consisting of a fuzzy nonsingular terminal sliding mode controller and a genetic algorithm is proposed in [46] for tip-position control of an uncertain two-link flexible manipulator. By the designed fuzzy controller, the input-output subsystem is guaranteed of fast convergence, strong robustness and perfect capability of eliminating chattering.

4. Conclusions

This research addresses fuzzy-logic method as an appropriate approach to control of mechanical robot manipulators. The method is explained and a review on applications of method in control of mobile robot and flexible links manipulators is presented.

Paper shows that FL provides a different way to approach a control or classification problem because this method focuses on what the system should do rather than trying to model how it works. Hence, one can concentrate on solving the problem rather than trying to model the robot system mathematically, if that is even possible.

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