Soft Computing Techniques in Intelligent Control: A Review

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Abstract— The reason behind this interest of Soft Computing Techniques for Intelligent Control from its advantages which are: it is suitable for linear and non-linear model, able to handle imprecise knowledge and ill-defined system, has the ability to convert the observations and the operator experience into mathematical model, combines both linguistic and crisp information in the same framework and it is more robust. In the present paper we review the soft computing techniques for three intelligent control techniques Fuzzy logic, Neural Network and genetic algorithm. We highlight the main difficulties and summarize the more recent developments in their policies.

Keywords — Soft Computing, Intelligent control, Fuzzy control, Neural Network, Genetic algorithm.

1. INTRODUCTION

With the rapid development and great progress in modern science and technology which have given a new and higher requirement to the system and control sciences, automatic control is faced with a new and strong challenge.

The traditional control including the classical feedback control, modern control and large-scale system theories has encountered many difficulties in its applications. First of all, the design and analysis for the traditional control system is based on their precise mathematical models that are usually difficult to achieve, owing to the complexity, nonlinearity, uncertainty, time varying, and incomplete characteristics of the exiting practical systems. Secondly, some critical hypotheses have to be put forward in studying and modeling the control systems. However, these hypotheses are not always practical. Thirdly, in order to increase the control performance, the complexity of the control system has also been increased. For these reasons, automatic control has been looking for a new way to overcome the difficulties it has been facing with in recent years. One of the more effective ways to solve the problem mentioned above is to use the technique of intelligent control-to-control systems. The core of the new way is the intellectualization of the controller, [1-3]. Figure 1 illustrates the developing process of the automatic control and increasing sophistication on the path to intelligent control.

Recent studies strongly stipulated that the intelligent controllers are the best candidates when the analytical design is tedious or is not satisfactory enough. In other words, if the control system possesses an intelligent controller, it may become easier to alleviate the adverse effects of time-varying behavior, noisy measurements or unmodeled dynamics, [4].

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![Fig.1 Development process of automatic control](image-url)
Intelligent control has been a great value both for practical and potential applications in wide areas. The advanced robots, automatic manufacturing systems, industrial production process, and space system are typical application areas of intelligent control. Intelligent control is one of the newest and most important areas where the computers are used to simulate human intelligence [1,4].

II. PROSPECTIVE OF INTELLIGENT CONTROL

It is without a doubt that during the past 10 years intelligent control has been rapidly developing and has gained wide applications. However, intelligent control is a new establishing discipline and is still incomplete both in the theory and applications.

II.1 Futures Research Issues of intelligent control

The advancement of related science and technology has given a powerful motivation to the discipline of intelligent control; inversely, the research and development of intelligent control have provided a suitable test-bed and application filed for all the mentioned areas. Figure 2 proposes a relationship among the related sciences, technology and intelligent control systems. The relationship that is necessary for the development of intelligent science including intelligent control [1].

In the field of automatic control, intelligent control has also played more significant roles. The control methods have been opened the door to a wide spectrum of complex applications; such complex systems are characterized by uncertainty, nonlinearity, and so on. The traditional control has encountered many difficulties in its applications, and the degree to which the control system deals successfully with the difficulties depends upon the level of intelligence in the system.

III. FUZZY LOGIC CONTROL

The way of injecting intelligence into a control mechanism the use of Fuzzy Logic which, was proposed by Zadeh in early 1960s, [5]. There are several reasons that make the use of fuzzy systems so attractive. Firstly, the procedure enables the designer to impose his/her feelings, intuitions or beliefs into the task space. Secondly, the fuzzy system models possess a great flexibility in choosing the methods of fuzzification, defuzzification and construction of rule base. Thirdly, the adaptability of the architecture makes it useful in fine-tuning of the parameters, [6].

Fuzzy control is an active research area of intelligent control. Zadeh presented his famous paper entitled “fuzzy sets” which brought froth the era of fuzzy control 1965, [5]. Since then, a great amount of research efforts have been carried out both in the theoretical investigations and practical applications. It is noted that the application intended research for fuzzy control has been made by many engineers and researchers, and has attained some interesting results since 1970s.

![Fig.2 Relationship among intelligent control systems and related S&T](http://www.researchpub.org/journal/jac/jac.html)

Fuzzy control systems are rule-based systems in which a set of so-called fuzzy rules represents a control decision mechanism to adjust the effects of certain causes coming from the system. The aim of Fuzzy control system is normally to substitute for or replace a skilled human operator with a fuzzy rule-based system. Figure 3 shows a block diagram for this definition. As shown, the human operator observes quantities by a meter or assessing a chart (i.e. noting Fuzzy variables) and then performing a definite action, such as pushing a knob or turning a wheel (i.e. providing a crisp action). In a similar fashion the Fuzzy controller, used crisp data directly from a number of sensors, though the process of fuzzification that converts these data into linguistic or Fuzzy membership function (Fuzzified). They then go through a set of Fuzzy “If-Then” rules in an inference engine much like an expert system and result in some Fuzzy output(s). The Fuzzy output(s) will be changed back into crisp values through a process called “defuzzification” by some weighted average method such as “centroidal” to get an approximate output value, [7].
P.N. Nikiforuk, P.R. Ukrainetz and Z. Hao [8], investigated the possibility of applying model reference adaptive control (MRAC) to a MIMO electrohydraulic servo system. The proposed scheme is based on estimation of the controller parameters obtained directly from input-output data. Even if the system does not satisfy the strict positive realness as in a non-minimum phase system, it is still possible to obtain asymptotically perfect model following. System simulation results are provided to illustrate the feasibility of the proposed adaptive control scheme.

T. Muto, P. Yu, Y. Takeda and H. Yamada [9], studied a self-tuning fuzzy controller (STFC) when it is applied to an electrohydraulic servo system. The whole procedure of the STFC is repeatedly performed until an acceptable level of control is achieved. The basic function of the STFC can be summarized as follows: (a) to issue appropriate control action while evaluating the performance, (b) to modify the control action based on the evaluation. It is verified by experiment and digital simulation that the STFC developed in this study is useful and effective for the control of electrohydraulic servo system.

W. Qingfeng, L. An and L. Yongxiang [10], presented an intelligent control of the electrohydraulic proportional cylinder. The self-learning intelligent control algorithm based on Fuzzy logic is given. Simulations and experimental show that the control performance of the proportional cylinder is satisfied.

M. Chang and S. Liaw [11], designed a Fuzzy logic controller and implemented it in a microcomputer to control the position of an electrohydraulic servo cylinder. Using the triangle shaped membership function, the normalised universe of discourse, and Tagagi and Sugeno’s reasoning for the controller; the position of the servo cylinder was successfully controlled.

K. Hiraku, T. Muto and H. Yamada [12], investigated the applicability of the Fuzzy control method for hydraulic servo system, which is composed of a 4-way spool valve and a load cylinder. As a result of experiment and simulation, it was confirmed that the control method could be applied with high accuracy along with high speed of response, in a region of considerably wide system parameters.

T. Zhao and T. Virvalo [13], proposed a new kind of state controller. The ideas of time optimal set point control and membership function are used in the design of the state controller, which we call fuzzy state controller (FSC). The FSC has been applied for the position control of a hydraulic servo. The control effects of ordinary state controller and FSC are compared for different strokes. The experimental results confirm that FSC is much more robust than the state controller when the position stroke is changed.

M. Efe, M. Fiskiran, O. Kaynak and I. Rudas [14], presented a novel training algorithm for adaptive Neuro-Fuzzy inference systems. A minimisation of parametric displacement together with a considerable improvement on tracking performance occurred. In the application example, control of a two-degree of freedom direct drive SCARA robotic manipulator is considered. As the controller, an adaptive Neuro-Fuzzy inference mechanism is used, and in the parameter tuning, the proposed algorithm is utilised.

K. Hayashi and A. Otsubo [15], presented design method of Fuzzy control systems depends on trial and error. Effective and convenient support tools for the study and design of Fuzzy control systems are in great demand as well as the establishment of design methods.

R. Mamlook, C. Tao and W. Thompson [16], presented a methodology for the reduction of complexity of the fuzzy if-then rules is performed by viewing the Fuzzy sets in the rules as crisp sets. The knowledge of the analysis is used to reduce the number of variables and the number of Fuzzy if-then rules. The simulation results show that the reconstructed controller is more efficient and performs as well as the original controller.

A. Trebi-Ollenu and B.A. White [17], introduced the adaptive Fuzzy controller as an outer feedback loop to increase the robustness of the I/O linearizing controller. A spacecraft attitude control problem is used to compare the technique with a conventional I/O linearizing controller.

H.S. Hwang [18], presented an approach to automatic design of optimal Fuzzy rule base for modeling and control using evolutionary programming. Five examples are examined. The performance of the identified Fuzzy models and Fuzzy controllers is demonstrated.

C. Li and R. Priemer [19], introduced a self-learning Fuzzy logic system for control unknown multiple-input-multiple-output (MIMO) plants. A random optimization algorithm is given to train the controller. A plant model is not required for training. Instead, training is guided by observations of plant responses to inputs.

J. R. Layne and K.M. Passino [4], introduced a theoretical study for controlling cargo ship steering by using FMRLC that depends on changing the final
controller output by adding direct correction for the final value based on defined model. They extended their theoretical study for the applications of two degrees of freedom manipulator.

III.1 Fuzzy Model Reference Learning Control (FMRLC)

For a complex plant has Multi Input Multi Output (MIMO) with high nonlinearity, the previous simple fuzzy logic controller will not be the hopeful controller. There is hardly need for a controller has the ability of simulation the human intelligent during the process. A “learning system” possesses the capability to improve its performance over time by interacting with its environment is shown in Figure 4. The “Fuzzy model reference-learning controller” (FMRLC), will tune and to some extent remember the values that it had tuned in the past, while the conventional approaches for linear systems simply continue to tune the controller parameters. Hence, for some applications when a properly designed FMRLC returns to a familiar operating condition it will already know how to control for that condition. Many past conventional adaptive control techniques for linear systems would have to retune each time a new operating condition is encountered, [20].

The learning mechanism tunes the rule base of the direct fuzzy controller so that the closed loop system behaves like the reference model. These rule base modifications are made by observing data from the controlled process, the reference model, and the fuzzy controller. The learning mechanism consists of two parts: a “fuzzy inverse model” and a “knowledge base modifier”, [21].

Ayman A. Aly designed an intelligent fuzzy ABS controller to adjust slipping performance for variety of roads. The fuzzy optimizer finds immediately the optimal wheel slips for the new surface and forces the actual wheel slips to track the optimal reference wheel slips. The simulation results show that proposed ABS algorithm ensures the avoiding of wheel’s blockage, even in different road conditions. Moreover, as a free model strategy, the obtained fuzzy control is advantageous from viewpoint of reducing design complexity and, also, anti-saturating, anti-chattering and robustness properties of the controlled system, [22].

IV. THE ARTIFICIAL NEURAL NETWORK TECHNIQUE

The artificial neural network models become very popular recently to overcome some of the limitations of analytical and other numerical methods in physical and dynamical modelling. ANN models have been used successfully to model complex nonlinear input-output time-series relationships in a wide variety of fields including finance, medicine, physics, engineering, geology, and hydrology. ANN models are capable of relating output to input variables for cases where no theoretical model works satisfactorily in a realistic time frame. An ANN is an information-processing paradigm inspired by the manner in which the heavily interconnected parallel structure of the human brain processes information, [23].

Training of ANN models, which can be based on experimental data and/or results from numerical models, typically implies adjustments of connection weights and biases so that the difference between ANN output and desired output is minimized. Figure 5 shows the architecture of the ANN model. The input layer comprises the nine input variables connected to neurons in the hidden layer through the weights assigned for each link. The number of neurons in the hidden layer is found by optimizing the network, [24].

IV.1 Back-Propagation Algorithm

Back-propagation learning is one of the most popular types NN learning methods. It has two operational phases. In first phase, forwarding phase, we send input data from input layer to the output layer. In the second phase, back-propagation phase, we calculate the error
(between target and output) and propagate the error backwardly to the input layer in order to change the weights of hidden layers by using the gradient descent method, [25].

![Fig.5. Schematic of the neural network model.](image)

The neural network is trained, using supervised learning, to develop an inverse model of the plant is shown in Fig.5, the network input is the process output and the network output is the corresponding process input. Inverse model are typically developed with steady state data and used for solve the problem of finding the swashplate angle which will produce the required flow rate whatever the pressure level.

Several studies have found that a three-layered neural network with one hidden layer can approximate any nonlinear function to any desired accuracy, [26]. The network consists of input layer, hidden layer and output layer. To explain the Back-propagation rule in detail a 3 layer network shown in Fig.6 will be used.

The performance of soft computing methodology, trained Neural Network (NN) based on the conventional PID controller, is used for the control of a swash plate displacement and compensates the effect of the backing pressure by implementing an inverse NN model. The feasibility of system is simulated and issue of implementation such pumps control is established. It is seen that the use of the proposed methodology results in some desirable characteristics, [25].

V. GENETIC ALGORITHM

Genetic programming (Koza, et al. [26]; Koza, et al. [27] and Reeves [28]) is an automated method for solving problems. Specifically, genetic programming progressively breeds a population of computer programs over a series of generations. Genetic programming is a probabilistic algorithm that searches the space of compositions of the available functions and terminals under the guidance of a fitness measure. Genetic programming starts with a primordial ooze of thousands of randomly created computer programs and uses the Darwinian principle of natural selection, recombination (crossover), mutation, gene duplication, gene deletion, and certain mechanisms of developmental biology to breed an improved population over a series of many generations.

![Fig.6 A training process flowchart](image)

Genetic programming breeds computer programs to solve problems by executing the following three steps:

1. Generate an initial population of compositions of the functions and terminals of the problem.
2. Iteratively perform the following sub steps (referred to herein as a generation) on the population of programs until the termination criterion has been satisfied:
   a. Execute each program in the population and assign a fitness value using the fitness measure.
   b. Create a new population of programs by applying the following operations. The operations are applied to program selected from the population with a probability based on fitness (with reselection allowed).
Reproduction: Copy the selected program to the new population. The reproduction process can be subdivided into two sub processes: Fitness Evaluation and Selection. The fitness function is what drives the evolutionary process and its purpose is to determine how well a string (individual) solves the problem, allowing for the assessment of the relative performance of each population member.

Crossover: Create a new offspring program for the new population by recombining randomly chosen parts of two selected programs. Reproduction may proceed in three steps as follows: 1) two newly re-produced strings are randomly selected from a Mating Pool; 2) a number of crossover positions along each string are uniformly selected at random and 3) two new strings are created and copied to the next generation by swapping string characters between the crossover positions defined before.

Mutation: Create one new offspring program for the new population by randomly mutating a randomly chosen part of the selected program.

Architecture-altering operations: Select an architecture-altering operation from the available repertoire of such operations and create one new offspring program for the new population by applying the selected architecture-altering operation to the selected program.

3. Designate the individual program that is identified by result designation (e.g., the best-so far individual) as the result of the run of genetic programming. This result may be a solution (or an approximate solution) to the problem.

Figure 7 shows the flowchart of the parameter optimizing procedure using GA. [29].

Initiation
Initially many individual solutions are randomly generated to form an initial population. The population size depends on the nature of the problem, but typically contains several hundreds or thousands of possible solutions. Traditionally, the population is generated randomly, covering the entire range of possible solutions (the search space). Occasionally, the solutions may be “seeded” in areas where optimal solutions are likely to be found. [30].

Selection
During each successive generation, a proportion of the existing population is selected to breed a new generation. Individual solutions are selected through a fitness-based process, where fitter solutions (as measured by a fitness function) are typically more likely to be selected. Certain selection methods rate the fitness of each solution and preferentially select the best solutions. Other methods rate only a random sample of the population, as this process may be very time-consuming. [31].

Mutation
Mutation is a genetic operator that alters one or more gene values in a chromosome from its initial state. This can result in entirely new individuals being added to the population. With these new individuals, GAs may be able to arrive at a better solution, [30]. Figure 8 shows the mutation process.

Genetic algorithms are used in closed loop systems to improve the performance of the system and to find best design parameters. Mehrdad has used GAs to design an adaptive PID controller, [27]. He used a Genetic Algorithm implemented in hardware for setting the K values of the PID Controller and minimizing the integral error in the system. Zhang designed a self-organizing genetic algorithm (SOGA) based tuning of
PID controller with good global search properties and a high convergence speed, [30]. Renato designed an optimal disturbance rejection PID Controller using genetic algorithms, [31]. He formulated the design as a constrained optimization problem. It consists of minimizing a performance index, i.e., the integral of the time weighted squared error subject to the disturbance rejection constraint. In this system we used the GA to find the best values of $K_p$, $K_i$, and $K_d$ of the PID controller to improve the system performance.

![Fig. 8 mutation process in GA](image)

**Fitness Function**

Fitness function is very important in system design using GA. The good formulation of fitness function helps in obtaining better results. Fitness function has been used in our system to increase the rise time and decrease overshoot and oscillation. The rise time and overshoot is measured numerically in simulation using numerical analysis method.

Ayman A. Aly designed a Proportional Integral Derivative (PID) controller and attached to electrohydraulic servo actuator system to control its angular position. The PID parameters are optimized by the Genetic Algorithm (GA). The controller is verified on the state space model of servovalve attached to a rotary actuator by SIMULINK program. The appropriate specifications of the GA for the rotary position control of an actuator system are presented. A new fitness function was implemented to optimize the feedback gains and its efficiency was verified for control such nonlinear servosystem, [32]. Also presented PD controller gain parameters optimized via Genetic Algorithm (GA). The cost function to be minimized is the time taken by the system to achieve a final desired position. The study shows that the GA gains selection policy is effective to set the PD controller parameters in handling the rigid spatial manipulators, [29].

VI. CONCLUSION

Real world systems are highly nonlinear control problem due to the complicated relationship between its components and parameters. The research that has been carried out in these systems covers a broad range of issues and challenges. Many different control methods have been developed and research on improved control methods is continuing. Most of these approaches require system models, and some of them cannot achieve satisfactory performance under the changes of various road conditions. While soft computing methods doesn’t need a precise model. A brief idea of how soft computing techniques are employed in intelligent control is given.

REFERENCES


Prof. Ayman A. Aly is the head of Mechatronics Section and the director of the E-Learning and distance education unit at Taif University, Saudi Arabia since 2008 and Editor in Chief of the International Journal of Control, Automation and System (IJCAS) since 2013. Prior to joining Taif University, He is one of the team who established the “Mechatronics and Robotics Engineering” Educational Program in Assiut University in 2006. He was in the Managing and implementation team of the Project “Development of Mechatronics Courses for Undergraduate Program” DMCUP Project- HEEP Grant A-085-10 Ministry of Higher Education –Egypt, 2004-2006. The international biographical center in Cambridge, England nominated and selected Ayman A. Aly as the International Educator of the year 2012 and Leading Engineers of the world 2013. Also, Ayman A. Aly nominated and selected for inclusion in Marquis Who's Who in the World, 30th Pearl Anniversary Edition, 2013. As, Taif University awarded him the prizes of excellence in scientific publication 2012, 2013 and 2014.

Ayman A. Aly is the author of more than 100 scientific papers and text books in Refereed Journals and International Conferences. He supervised some of MSc. and PhD. Degree Students. His main areas of research are Robust and Intelligent Control of Mechatronics Systems, Automotive Control Systems, Thermalfluid Systems Modeling and Simulation.