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A Review in Applications of Control Engineering Based on Genetic Algorithm

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ABSTRACT

The most popular evolutionary search techniques are genetic algorithms (GAs). Even though they are frequently used to solve control engineering problems, they are currently not a common tool in the control engineer's toolbox. This may be due in part to the fact that there are currently few general overviews of the employment of GAs for control engineering problems, and that they are often reported on at computer science conferences rather than conferences for control engineers. This review study is intended to assist researchers and practitioners in identifying prospective research issues, potential solutions, as well as advantages and disadvantages of each technique. This study gives a brief overview of contemporary a Genetic Algorithm (GA) in control systems. Additionally, offers a number of control techniques used with the GA that have undergone extensive research. The conclusion of this study listed in a table to show the effectiveness of GA in various control technique and which field didn't used till the time of preparing this review.

1. Introduction

A well-known algorithm that draws inspiration from the biological evolution process is the genetic algorithm (GA). This algorithm imitate Darwin's principle of the "survival of the fittest" in the natural world [1]. J.H. Holland invented GA in 1975 [2]. It has attracted considerable and a lot of interest. Many various fields, including signal analysis, gaming, automation, image analysis, planning, and control engineering, utilize GAs. Evolutionary programming (EP), evolution strategies (ES), and genetic programming (GP), are evolutionary techniques similar to GAs that are comparable in their processes and strategies but differ mostly in implementation details. The borders between these distinct evolutionary techniques have somewhat eroded in recent years as researchers have combined elements of the various algorithms.

Several conference proceedings and publications have papers on the use of GAs in control engineering. They include PID control, optimum control, adaptive control, resilient control, and system identification, among many more types of control. However, there aren't many general studies of GAs in control engineering. Future applications in this area are anticipated as well as key GA properties and their significance to control engineering issues are studied. The main contributions of this review are the use of GA and hybrid GA with another controlling technique in order to control some performance factors such as stability, the robustness, the transient and steady state of the system specifications. The rest of the paper is arranged as section 2 presents the specifications of genetic algorithm, The use of GA in control engineering is presented in section 3, which include the PID controller, intelligent controller, robust controller, adaptive controller. Finally, the conclusion remarks are presented in section 4.

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2. Specification of genetic algorithms

GA is a search and optimization method that originally came from two biological concepts which are "natural selection" and "natural genetics". In contrast to conventional search algorithms, GAs influences a population of potential solutions for a problem rather than simply one potential solution.

Individuals or chromosomes, and the population's possible solutions are encoded representations of all the variables of the solution [3] . A fitness rating is given to each chromosome to indicate the effectiveness of this specific solution as compared with the other chromosomes in the population. The GA uses so-called "genetic operators," such as crossover, and mutation to build new chromosomes from the ones already present in the population, either by combining of two or more parents' chromosomes or by altering an existing chromosome, in order to develop chromosomes that encode better solutions. The method for parent chromosome selection takes into account the fitness of the parents which guaranteeing that the better solutions have a higher probability of reproducing, and passing on their beneficial traits to their offspring. Over time, the existing individuals are replaced by newly created ones. After some time, the populace will arrive at the "best" solution through this procedure. Because all optimization techniques must have a good fitness function in order to perform, GAs are generally applicable [4].Therefore, the use of GAs are best suited for issues for which there is a lack of an effective dedicated solution mechanism.

3.The use of Genetic algorithm in control engineering

The inability to select values for a large number of control parameters in a systematic and comprehensible manner is undoubtedly a major barrier to creating an effective control system. Therefore, the performance of the system depends heavily on the controller's structure and settings. This reliance, typically cannot be represented in a mathematical formula. Additionally, there frequently needs to be a made in the midst of competing performance challenges. It is evident that a main challenge to creating a satisfying control system is the absence of a methodical and intuitive approach to choosing values for a variety of control parameters. By defining a fitness indicator as a function from over performance requirements and encoding the system and parameters of such controllers together into chromosome, GA is used to solve these problems. This formulates the design problem as the minimization of an objective system with regard to the controller parameters. GAs can be used to carry out this search because they simply require a fitness function to manage the optimization process. Real engineering control problems can be solved with the use of a strong tool created by GAs. The major of this section will focus on the application of GAs to specific control topic These topics classified as:

3.1. PID controller

A.Jayachitra and R. Vinodha [5] presented an optimal PID controller parameter using GA and objective functions which are combined of integral absolute error (IAE) integral square error (ISE), and integrated time absolute error (ITAE), this controller used with the process of a continuous stirred tank reactor (CSTR). Based on the results of the simulation studies, The authors concluded that the optimized controller parameters produced by using GA and a weighted combination of ITAE, ISE, and IAE as an objective function have successfully achieved acceptable set point tracking and disturbance rejection throughout the entire operating range of the CSTR process.

A. Abdollai and et al. [6] proposed the best approach for controlling, stabilizing, and providing control performance of the quadrotor's attitude subsystem. The Proportional- Integral Derivative (PID) control is the foundation of the controller, and the Genetic Algorithm approach is used to optimize the PID controller's parameters. The transfer function of second order for the attitude is structured to accomplish the desired outcome. Time domain parameters are used to assess the designed control structure's performance such as the error steady state, the overshoot, settling time and rise time. Both the output response criteria and the magnitude of the input control signal are included in the fitness function for GA implementation. Where the reference inputs are simulated for sinuous and square input signals to get the results. Integrated absolute error and control effort comprise the fitness function for GA. The value of PID controller, to control the attitude angle of quadrotor, is chosen by using GA. The simulation results showed how the applied control method is effective in both great tracking performance and optimality control input. L. Shao and et al. [7] suggested a GA to tune the PID controller parameters, this algorithm used Heat transfer station, in the centr part the heating system for temperature control system. The results showed that performance will be better when the PID is tuned using a GA as opposed to using previous techniques in terms of overshoot, settling time and stability.

3.2 Intelligent controller

Gyula Mester [8] proposed optimizing the fuzzy logic controller based on GA to control the four degrees of freedom of SCARA robot. Where, the researcher designed a fuzzy joint-space controller depends on GA without requiring knowledge of the robot's parameter values or mathematical model. For the optimization of membership functions, scaling factors, and fuzzy rules, simple GA are used. The effectiveness of the suggested strategy is demonstrated by the outcomes of the computer simulation used with the four-degree of freedom of SCARA robot.

Ahmed J. Ali, and Ziyad K. Farej [9] Proposed the use of fuzzy logic controller based on genetic algorithm to reduce the time period of the optimizing error signal gains, the researchers used this hybrid controller for monitoring a three-phase induction motor's (IM) speed under various operating circumstances. MATLAB software was used to build, model, and simulate the proposed controller FL with GA under various load torque motor operating conditions. according to the results, the use of a hybrid FL/GA algorithm control technique clearly improves the performance of the induction motor, the maximum value for the efficiency of the closed loop system response under the controller was 95.92%. While the GA proved its effectiveness in speeding up the process of choosing the gain values, the system's performance is improved by 14.42% in terms of efficiency compared to that of an open loop system.

Antoni Swi´c and et al. [10] provided a novel artificial intelligence-based machine learning strategy for automating the control of low-rigidity shaft. On the basis of several neural network types and genetic algorithms, three approaches of hybrid controllers were created. The goal of the genetic algorithm was to choose the neural network's input parameters that will result in the least amount of deviation. A traditional multilayer neural network, a nonlinear autoregressive network with exogenous input (NARX) prediction network, and a deep recurrent long short-term memory (LSTM) network were all tested to see how well they performed. The experiments' successful outcomes supported the usefulness of the suggested approach for regulating low-rigidity shaft turning. Where the neural network based on GA proved its effectiveness of optimization.

Qingsong, and et al. [11] developed a novel control for the Boost converter which combines GA and PID control from a back propagation (BP) neural network to enhance the converter's dynamic response and stability performance. Where, BP neural network coupled with a genetic algorithm by combining the global optimization capabilities of genetic algorithms with the adaptive adjustment properties of BP neural networks, PID control (GA-BPPID) was presented to enhance the dynamic and anti-interference performances of the Boost circuit. The goal of GA was to improve the BP neural network's initial state. The process for system modeling and its design was presented. The gradient descent approach can be used to change the weight of each layer in the three-layer BP neural network that was chosen for the design Finally, simulation was used to verify the theoretical analysis and controller design. Where the GA-BPPID controller's optimized performance based on GA was seemed the best. The adjustment of the controller parameters, particularly when handling complicated objects was more adaptably, as well as on-line parameters adjustment.

it has been determined that the proposed GA-BPPID controller not only significantly reduces the overshoot and settle time of the output voltage but also improves the stability and anti-interference performance of the system by observing the output voltage of the Boost circuit under three different controllers and the waveform results under specific interferences.

3.3 Robust control

J. P. Belletti Araque and et al. [12] designed a hybrid approach for the attitude control system of the medium-size launch vehicle (LV), where a genetic algorithm (GA) was used to optimize a structured

H∞ controller. The research objective was to decrease design effort while ensuring performance and robustness characteristics that were on equivalent with or better than those attained by more traditional methods in the creation of launch vehicle flight control system (LVFCS). The resultant solution satisfied bounded stability margins, attitude tracking abilities, wind-gust disturbance rejection, aerodynamic load relief, and reduced control actuation

This approach was able to design a controller with performance that is equivalent to or even better than the structured H∞ synthesis, while requiring just a very basic understanding of the LV system in a relatively short length of time. M. J. Mahmoodabadi and et al. [13] presented a reliable adaptive control strategy for a class of fourth-order systems. This controller used a decoupled sliding mode control (DSMC)approach combined with a feedback linearization (FBL)technique as its structural basis. The feedback linearization approach was used to create a linear control law with adaptive coefficients, and the decoupled sliding mode was applied to ensure the sliding condition. The weighting summation of the decoupled sliding mode and feedback linearization controllers was used to define the final control effort. Next, the multi-objective genetic algorithm was used to optimize the controller coefficients. FBL and DSMC ware implemented simultaneously, and the coefficients of the FBL controller were set using an approximation of the gradient descent method to satisfy the DSMC method's sliding condition. the control parameters were generated using the multi-objective genetic algorithm optimization (MOGA) to reduce the integral of time times absolute error (ITAE).

The control approach was applied to handle the cart-pole, ball-beam and wheel systems to study the robustness of the controlling system. The outcome of the research proved the effectiveness, dynamic responses achieved from the suggested controller were substantially faster, and the values of ITAE were reduced. Hoang Chinh Tran and et al. [14] proposed Linear Quadratic Regulation (LQR) combined with GA to control the system of acrobot robot which is under actuated system. Double links are used to define the Acrobot Robotic System, a down link (link1) and an up link (link2). During link1 with link2, a control motor (active joint) connects the two links through a joint with the terminator can freely move around a latent joint. The results showed that the LQR controller combined with GA can regulate a plant that maintains a balanced condition with a system is transient for a short duration of time.

Lyapunov stability control technique combined with genetic algorithm was presented by Karim Ben bouabdallah and Zhu Qi-Dan in 2013 [15] to study the problem of tracking movement of mobile robot. This approach computed the movement and angular velocities to control the orientation and movement of the robot due to the target. This method, in which the mobility of the target was highlighted in the system modeling and the controller design. As a result, the motion of the target was not taken into account while creating the first controller, but it is when designing the second controller. Then, a better variant of the second controller was created by using a genetic algorithm to optimize the coefficients that occur in the control laws, leading to increase robot performance and high controller efficiency in terms of the rate of tracking error convergence and trajectory smoothness. The outcomes of simulations were then shown to demonstrate the applicability and efficacy of the suggested control strategy. where the incorporating of the target's motion into the design of the control rules enabled the robot to track the moving target without steady state error or delay time.

A genetic algorithm with stochastic replenishment intervals for controlling system was presented by Ata Allah Taleizadeh and et al. in 2010 [12] [16] . This approach was used with the model of multiperiodic inventory control of mixed integer-nonlinear programing type. There are two main assumptions in situations of involving multiperiodic inventory control. The first is the continuous review, where orders may occur at any moment, depending on the inventory level, and the second is the periodic review, where orders may only occur at the start of each period. These presumptions were eased in this study, which assumes that the intervals between two replenishments are dispersed randomly using independent, identical random variables. Both genetic algorithm and simulated annealing methods were used to solve it. Two numerical examples that showed the applicability of the suggested approaches and show that the genetic algorithm method outperforms simulated annealing in terms of objective function values are provided at the conclusion.

3.4. optimal control

The optimization control approach proposed by M. Mossolly and et al. [17] to optimiz the HVAC (heating, ventilation, and air conditioning) systems for energy consumption. This strategy was examined how various HVAC optimal control tactics affect energy usage in a current, typical air conditioning system in Beirut while maintaining comfort and indoor air quality (IAQ). The energy cost minimization problem for each examined control approach had been solved using optimization employing genetic algorithm techniques built on MATLABs, which also had been utilized to estimate the HVAC system's optimal set points under transient responce. Due to this control approach, the energy savings was enhanced up to 30.4%.

A machine learning-based strategy to quantum state technique depend on genetic algorithms was employed by Jonathon Brown, Mauro Paternostro and et al. in 2022 [18], this strategy was utilized to improve the couplings of functional time-dependence and the fidelity between the evolved state and various objectives. The authors reviewed the effective Hamiltonian network of a group of jointly of non-interacting qubits handled by a driving bus, and used a genetic algorithm to find the best collection of pulses to power the development of the qubit register. These findings demonstrate that genetic algorithms were an efficient method for controlling large-scale quantum systems.

3.5 Adaptive control

adaptation and self-adaptation mechanism with differential evolution was presented by Aleˇs Zamuda and Janez Bresti in 2015 [19], this mechanism concentrating on the iteration-temporal randomness of the self-adaptive control parameters. The paper also discussed how and when the mechanism created new values for the control parameters. in specific dimensions. While, the self-adaptive parameters adjustment of a GA was proposed by Eric Pellerin, Luc Pigeona and et al. [20] to encoded the control of a GA's parameters into the chromosome of each individual. The research showed that, a GA can figure out how to change its parameters by itself. The outcomes also showed that the GA performed better when different genetic operators were self-selected. The combination of parameters with other factors, interaction with the problem, and the evolution mechanism were employed to achieve this parameter selection. These findings point to a promising strategy for creating GA with self-adaptive parameter settings, which do not require pre-adjustment of the parameters. Whereas, Model Reference Adaptive Control (MRAC) to an Automatic Voltage Regulator (AVR) was presented in 2013 by Norelys Aguila-Camacho and M. A. Duarte-Mermoud [21].

The parameters of this controller were tuned based on fractional order differential equations. In this work, four realizations of the FOMRAC were developed, with each one taking various orders for the plant model into account. The design process involved applying genetic algorithm optimization to find the ideal values of the fractional order and the adaptive benefits for each adaptive law. This control strategy demonstrated an improvement in the controlled system's response qualities and robustness depended on the model uncertainty.

4. Conclusion

The GA is used to tune the unknown parameters of the controller in some research as compared with the traditional technique. GA proved its effectiveness to select the optimum parameter for the controller. This leads to make the system more stable and get better performance in tracking the set point. In addition, GA provides an advantage over most conventional techniques for handling uncertainty and non-linear systems. Where it is used with complicated objects to be more adaptable. Therefore, the conclusion of this study that control engineers should consider about using GAs when they encounter a control challenge that the standard methodologies can't handle very well. Table (1) shows the remarks that will be finding when prepared this review study in utilizing GA in the field of control system

Table 1. The indexed remarks based on each controller

Type of controller with genetic algorithm	Indication of stability	Indication of disturbance rejection	Performance
PID	Effective	Acceptable	Great in terms of overshoot, settling time
Intelligent controller using fuzzy	Effective	Not used	Improved
Intelligent controller using neural network	Improved	Not used	Effectiveness in terms of overshoot, settling time
Robust controller H∞ controller	Improved	Ability	Effectiveness to get better performance
Robust controller Slid mode, linear quadratic, Lyapunov	Improved	Not used	Effectiveness to get better performance
Optimal controller	Improved	Not used	Effectiveness to get better performance
Adaptive controller	Improved	Not used	Effectiveness to get better performance

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