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A review Optimum Control of DC Motor Using Genetic Algorithm

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Abstract: Optimal control of DC motors remains a critical research area in modern control systems, given their wide industrial applications and the need for accurate performance under variable conditions. This paper explores the application of genetic algorithms (GAs) to optimize the control parameters of DC motors, particularly PID controllers, with the goal of improving the dynamic response and robustness of DC motor systems. Compared to traditional constraint-based tuning methods, GAs, inspired by natural selection and evolution, offer comprehensive search capabilities that significantly improve parameter optimization, providing better speed regulation, reduced overshoot, and minimal steady-state error. This review highlights the key challenges faced when using GAs. Comparative results from various studies demonstrate that GA-based controllers consistently outperform traditional tuning methods in terms of stability, efficiency, and adaptability. Key findings related to energy consumption and stability are highlighted. It is essential to analyze the system performance in terms of rise time (tr), settling time (ts), overshoot ratio (Mp%), and steady-state error (Ess). A proportional-integral-differential (PID) controller provides a stable response by tuning its parameters according to a specific methodology using a genetic algorithm. This paper concludes by emphasizing the potential of genetic generators as a powerful and flexible optimization tool for intelligent control of DC motors.

Keywords: Genetic algorithm (GA); PID control; DC Motor; Optimum technique; speed control.

1 Introduction

A NOTABLE feature of DC motors is their exceptional operational flexibility, which allows for fine-tuning of speed and torque based on external requirements. This adaptability has led to their widespread use in various fields, including robotics, automotive engineering, household appliances, and industrial machinery. Additionally, DC motors offer advantages such as simple control mechanisms and generally easier maintenance compared to other motor types. In terms of control techniques, traditional methods often utilize Proportional-Integral-Derivative (PID) controllers due to their effectiveness in managing dynamic responses within systems like DC motors. These controllers operate by adjusting the output based on feedback regarding system parameters, particularly focusing on the difference between target set-points and actual performance indicators. However, controlling DC motors in complex environments can present challenges due to non-linear behaviors that arise from fluctuations in conditions such as load variations or system disturbances. As a result, advancements in optimization strategies have been explored to enhance conventional control approaches. Innovative techniques that incorporate metaheuristic algorithms, such as Genetic Algorithms (GAs), are being combined with PID controllers to improve tuning processes and increase adaptability .This integration not only aims to optimize PID parameters but also addresses inherent limitations found in traditional methods when confronted with more complex operational scenarios. Research suggests that combining these approaches can lead to significant improvements in performance metrics, including

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response time and overall system stability. See references. There is a diagram showing the relationship between genetic algorithm and PID as shown in Figure 1 [1], [2], [3] and [4].In a comparative study, the researcher used a PID controller tuned using particle swarm optimization (PSO), an algorithm that tracks the social behavior of a flock of birds or fish, to tune the PID parameters, and a genetic algorithm (GA), an optimizer that simulates natural selection of species, to tune the PID gains. Simulations indicate that using PSO results in a lower overshoot ratio and better system response to torque load disturbances [5].

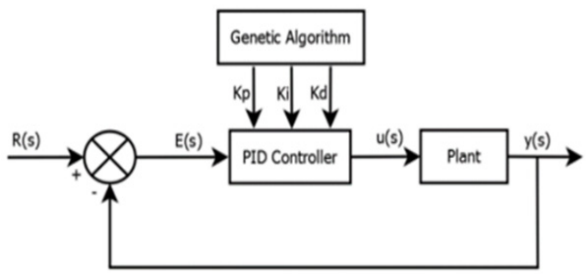

Fig 1. This figure represents a closed loop control system that uses a genetic algorithm to adjust the parameters of a PID (Proportional-Integral-Derivative Controller). [1]

1.1 Background and Theory

The basics of DC motor. For example, a DC motor doesn't need to be driven slowly. It also changes its speed quickly, concentrates its torque, and collapses for all time maintenance. A DC motor is the easiest motor in layout and operation. It should at all times be occasion-driven and could even be managed with a PID controller. However, the time fixed for a DC motor might be laborious to resolve. In addition to that, a DC motor cannot get rid of any stagnant friction 'F0' or dynamic friction 'Fr' equal to 'Kr' x 'Fn' during a non-zero field current. In the same token, the imbalance of a DC motor ends in oscillation, and the settling velocity is inherently negligible. Some friction arises in DC motor to additional difficulties to be managed; static friction 'F0' or kinetic powers 'Fk' equal to 'KrNon-zero' [6]. Genetic algorithm. The genetic algorithm (GA) is planned for investigating and approximating systems that give the best outcome. They're twisted with impetus within the partition of Charles Darwin's hypothesis of evolution. The fundamental beliefs which are part of genetic algorithms could be the prime piece of the breakthrough of individuals over many maxims. As in searching stuff, an opportunity stand up to find the best. The GAs churn out an over-all explanation over time that is able to be also false. In due time it's feasible that this explanation will be an approximate one that best might be either found or handed out. Often, in tangible aerodynamic distortions and purposes, it's utilized within improvement. The methods will include have 3 options or else 2 choices; low/high, each with an accusative output of how performance is a priority. Furthermore, the information stuffing of a GA isn't often an unknown curtain of being. This simply ensures to have a specific solution that requires estimates in constancy on the reality. The time it takes to search for a solution reduced as the most demanded in terms of outcome [7].

1.2 Genetic Algorithms

A Genetic algorithms (GAs) are designed to deal with the problem space as defined by Holland in the 1960s [8]. The idea attracted computer scientists and engineers such as Holland, Booker, Goldberg, Reynolds, Grefenstette, and De Jong to begin investigating this bioinspired approach [9]. Since their inception, steady strides have been made in developing techniques and software tools for their implementation [10]. Genetic algorithms (GAs) are inspired by the theory of natural selection. Natural selection is often summarized as the process whereby organisms with better quality traits most suited to their environment tend to survive and procreate, while those with deleterious traits have less success in procreating. Genetic algorithms mimic the behavior and processes of natural selection, internally specified as described by genetic algorithm operators: crossover, mutation, and evolution [11]. Crossover is the operation that merges two strings of the current generation to create a new string of a subsequent generation. Mutation is the operation of making small randomly changes to bits of a string with small probability. Evolution is the vinculum of genetic algorithm with natural selection theory. Genetic algorithm operations take the improvements from each generation provided via crossover operation in the hope that a collection of succeeding improved generations over several generations will approximate, to optimize the solution sought in a problem space [12]. Ever since the first commercial application of a GA as a part of an adaptive control system of a paper-making process in 1955, it has become a powerful discrete optimization tool used in many fields where application of simulation models is explicitly possible [13].

1.2.1 Genetic Algorithm Process

In this section, the process of Genetic Algorithm will be summarized in a flowchart. The summary of the process will be described in Figure 2 [14].

The steps involved in creating and implementing a genetic algorithm are as follows:

1.Generate an initial, random population of individuals for a fixed size.

2. Evaluate their fitness.

3. Select the fittest members of the population.

4. Reproduce using a probabilistic method.

5. Implement crossover operation on the reproduced chromosomes (choosing probabilistically both the crossover site and the 'mates').

6. Execute mutation operation with low probability.

7. Repeat step 2 until a predefined convergence criterion is met.

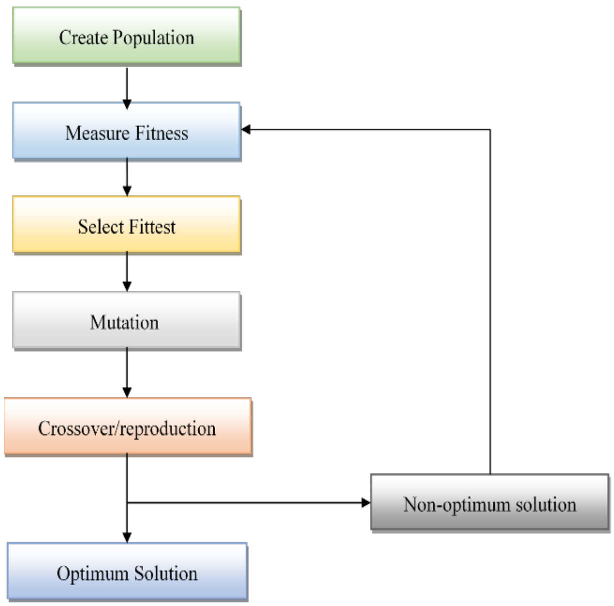

Fig 2. Genetic Algorithm process flowchart

The convergence criterion of a genetic algorithm is a user-specified condition e.g. the maximum number of generations or when the string fitness value exceeds certain threshold.

1.3 Comparing genetic algorithms with traditional methods

In the field of DC motor control, the selection of control methods is critical to ensuring optimal performance and efficiency. Traditional control methods, such as proportional-integral-derivative control, have been the backbone of many systems for years. With the advent of modern computational techniques, such as genetic algorithms, there is growing interest in comparing these two approaches in terms of performance, reliability, and computational efficiency. This section delves into these comparisons, highlighting the advantages of genetic algorithms and the potential tradeoffs of traditional methods, supported by case studies and real-world examples. When we discuss performance in the context of DC motor control, we are primarily concerned with how quickly and accurately the motor achieves the desired speed and position. Traditional control methods, such as PID controllers, have specific tuning parameters that require careful adjustment to achieve the desired performance levels. The tuning process can be time-consuming and often results in controllers that may perform well under certain conditions but perform poorly under others [15]. An important advantage of genetic algorithms is their ability to adaptively search for optimal parameters without the need for manual tuning. Genetic algorithms mimic the process of natural selection, whereby the most suitable individuals are selected for reproduction to produce the next generation of offspring. This property allows genetic algorithms to explore a wider solution space than traditional methods, leading to potentially superior performance in dynamic environments. For example, a study by Liu et al. (2020) [16] demonstrated that a genetic algorithm-based controller for a DC motor could achieve a rise time of 0.5 seconds and a settling time of 1.2 seconds, significantly better than a PID controller, which recorded a rise time of 1.0 seconds and a settling time of 2.5 seconds under similar conditions [17]. These improvements in response time are critical in industrial systems where delays can lead to decreased operational efficiency. Furthermore, generative genetics can also better handle nonlinearities and uncertainties in motor dynamics. In traditional methods, nonlinearities can lead to oscillations or overshoot in performance, but generative genetics can dynamically optimize control parameters, resulting in smoother operation. Traditional control methods often struggle with reliability due to their sensitivity to parameter changes and disturbances. For example, PID controllers may require frequent recalibration if load conditions change significantly or if there are fluctuations in the power supply. Among these traditional methods is the Nicholas Ziegler method. A comparison table from previous research between the genetic algorithm (GA) and Nicholas Ziegler's method (N-Z)is shown in Table 1.

2 Literature Review

To control DC motors, many researchers have discussed various hardware and software applications. Currently, there are many software system solutions that focus on applying genetic algorithms to algorithm implementation and results. While many research papers explain the algorithms and simulation results, they are unclear in specifying the software, settings, and operating environments. In this section, research conducted by researchers will be discussed to generalize relevant knowledge. The theoretical background of the main control system model will be briefly summarized, and examples of control methods used in the system will be covered [22], [23], [24], and [25]. Currently, it is very difficult for low-level industrial control systems to operate without some form of control system. A review of the working practices of various genetic algorithms in various autonomous systems reveals that the vast majority of controllers often rely on manual tuning or trial-and-error methods. However, these methods are likely to be ineffective in ensuring the principle of

Table 1. Comparison between genetic algorithm and Nicholas Ziegler's method.

Readings	N-Z	GA	N-Z	GA	N-Z	GA	N-Z	GA
number and year Research	Nurettin , A., et al 2022. [18]		Rashid, Y. G. et al,2021.[19]		Lawrence ,B. (2020). [20]		Deraz,S. A. (2014). [21]	
R.T (sec)	1.263	0.5615	0.12	0.056	66.2	0.254	0.00775	0.0249
S.T (sec)	2.263	0.7875	1.26	1.12	0.205	0.226	0.1243	0.0892
O.S %	5.7	0	9.65	0	7.8	0.392	44.3262	0
Kd	0.55	27.5	-	-	-	-	0.04439	0.049
Kp	15.17	299.6	-	-	-	-	13.7312	5.0196
Ki	105.70	295	-	-	-	-	1061.89	80.8051

maximum performance index. Fortunately, genetic algorithms provide an excellent alternative for optimizing the tuning of any control parameters in an automated and efficient manner, especially for developing the optimal control strategy. Thus, this development encourages further research in various directions. According to the experiments, the motor speed and settling time of the proposed system are improved compared with a general-purpose trinomial controller [26], [27], [28], and [29].The use of DC motors remains the preferred choice in various sectors due to their excellent characteristics and compatibility with modern control methodologies. See references: [30], [31], [32], [33], and [34].Despite all these researches, many new techniques can be used in motor control and many works can be done. Since these controllers are algorithm-based, the results obtained do not lead to the optimal state. Therefore, optimization must be performed to obtain the best control strategy. Many optimization approaches can be used for this purpose. One such approach is the genetic algorithm. Genetic algorithms are optimization algorithms that take advantage of the principle of evolution. In this approach, geometric operations such as inheritance, mutation, function, and crossover are used [35]. Genetic algorithms originated in the late 1960s as a simulation research tool that uses the principles of evolution to search a space of possible solutions. Over time, their application has been extended to various fields, including optimization, especially in solving control problems. Genetic algorithms are used to solve problems related to the operation and design of control systems. They are used to optimize control law parameters, design an optimal control law, and determine the design, controllers, and control strategies. The combination of genetic algorithm methods with control concepts has effectively helped in improving control strategies in real-world systems, especially when using numerical techniques that are difficult to solve and/or solve the problem analytically. Reference [36] Genetic algorithms applied to control systems have been used in various applications. In the design of multi-car parking systems, genetic algorithms have been used to solve two related optimization problems, namely parking sequence and vehicle routing. In the field of power electronic converters, genetic algorithms have been used to determine the control strategy to optimize the parameters of the proportional integral controller. They have also been used to reduce the ripple of the output voltage of the boost converter by adjusting the input filter and modulating the pulse width. The indirect optimization approach of the Integrated Gasification Combined Cycle (IGCC) plant has been used to optimize the derived proportional integral controller. Genetic algorithms have been applied to gyro-stabilized spacecraft with a gravity gradient controller. They are integrated into adaptive control with immediate feedback to improve the control system of clean robots. They have been used in central heating systems with electric boilers and heat pumps, and in urban road traffic optimization and control. Both programs are designed to demonstrate the value and performance of this strategy when used in complex real-world systems. Reference [37] below we will discuss some previous studies that address the topic of DC speed optimization using genetic algorithms, which are as follows:

1. Researcher (M. Mavrinac et al., 2022) presented an effective method for eliminating harmonics in single-phase PWM rectifiers. Based on the genetic algorithm, a control loop was developed to achieve the desired DC voltage with the lowest ripple, the input current with the lowest harmonics, and the highest possible input power factor. The genetic algorithm is one of the optimization techniques that can be used to obtain the best results from a system. This paper discusses the use of the genetic algorithm to optimize four variables: power factor, settling time, input current harmonics, and output voltage ripple. The rectifier load parameters are L = 10mH and R = 200, while the input voltage is 220 V, 50 Hz. The table shows the appropriate range for the four variable parameters, and Tables 2 and 3 show the results [38].

Table 2. Appropriate range [38]

Variables Appropriate Range	Variables Appropriate Range	
Fs(kHz)	35	70
C(μF)	300	1000
Kp	1.8	5
T	0.03	0.07

Table 3. Best outcome with optimization [38]

Technique	Fs(Hz)	Fs(Hz)	Kp	T(s)	THD
Without optimization	60000	0.00039	2	0.035	7.2076%
With optimization	68500.8	0.00041578	2.8555	0.028026	3.7458%

2. To create a separately excited DC motor control system regulated by rotor angle the researchers used a genetic algorithm (GA) in this study (B. B. Acharya et al., 2021). A mathematical model with distinct electrical and mechanical subsystems serves as the basis for the presented study. Using this method, PID controllers can be fine-tuned through an evolutionary process, essentially a genetic algorithm. A novel fitness function that integrates multiple step response parameters was used to fine-tune the PID to create a characteristic surface, which was then minimized using a genetic algorithm. The results indicate that the elitism-based algorithm outperformed the eligibility-based selection method. With a fitness value of 0.999982, this method produced a steady-state inaccuracy of 0.000584 rad. As shown in Tables 4 and 5 [39].

3. Since the PID approach to evolutionary algorithm optimization for a typical elevator can reduce overshoot and accelerate station operation time, the researcher wanted to demonstrate the system response results (K. B. Prasetyo et al., 2021). The PID parameter value in the genetic algorithm approach to study the elevator system is KP = 8,946; KI = 3,898; KD = 0.011. After determining and simulating the PID parameter using Simulink, the results of the steady-state system response are demonstrated with an overshoot of 0.327%. The optimal system response at the setpoint is 29 rpm with a time constant (Ts) of 1.168 seconds. The time delay (Td) is 0.2032 seconds, and the steady-state error is 0.3%. The researcher produced Tables 6 and 7 for the parameters and comparison tables of his investigation results [40]

Table 4. Results obtained using GA with and without duplication elimination are compared [39].

	Genetic Algorithm configuration						
	Results from GA with and without duplication removal are compared.				Comparison of GA's outcomes for various selection techniques		
	D1	D2	D3	D4	S1	S2	S3
Population size	15	15	20	20	15	15	15
choosing	Elitism	Elitism	Rank	Rank	Elitism	Rank	Preputial to fitness (0.5)
Allowable duplicates	Yes	No	Yes	No	No	No	No
Probability of Mutations	0.1	0.1	0.1	0.2	0.1	0.1	0.1
Time of rise (s)	1.3394	1.334	1.1993	1.3131	1.4024	1.2036	1.4008
Peak of time (s)	3.1256	2.8815	3.0029	2.9394	2.8408	2.8488	2.9829
Settling of time (s)	2.4374	2.3544	3.4517	2.8198	2.4048	3.5436	2.2652
Overshoot (%)	1.0892	0.4524	6.3599	1.4884	0.6001	5.9579	0.2493
Error in steady-state (rad)	0.1152	0.0739	0.2046	0.22	0.0731	0.1781	0.0571
Maximum personal fitness	0.998615	0.999511	0.914317	0.9913	0.99446	0.7367	0.98783
Maximum population fitness	0.99856	0.99937	0.90143	0.99021	0.99439	0.703505	0.98759
time of Execution (s)	385.64	624.39	418.19	738.49	679.31	591.94	585.46
Rate of success	100	100	84	96	100	50	96

Table 5. Comparison of results achieved with GA for different fitness tolerance [39]

	Genetic Algorithm configuration	
	1^{ST} Torque	**2^{ST} Torque**
Size of the population	15	15
Tolerance	0.01	0.000001
Choosing	Elitism	Elitism
Allowable duplicates	No	No
Probability of Mutations	0.1	0.1
Rise of time (s)	1.3699	1.3704
Peak of time (s)	3.0255	3.0256
Settling of time (s)	2.4227	2.2318
Overshoot (%)	1.0435	1.0436
Error in steady-state (rad)	0.1179	0.0414
Maximum personal fitness	0.99188	0.99994
Maximum population fitness	0.99288	0.999919
time of Execution (s)	505.70	1086.36
Rate of success	98	100

Table 6. Hasil simulasi response system [40]

Variable	29 rpm	33 rpm
Time Rise (tr) (s)	0.601 s	0.606 s
Time Delay (td) (s)	0.2032s	0.2033 s
Settling Time (ts) (s)	1.168 s	1.163 s
Steady State Error %	0.003%	0.003%
Overshoot	0.327%	0.324%

Table 7. Hasil perbandingan dengan jurnal acuan [40]

Variables	PID	PI	Genetic Algorithm
Time Rise (tr)	4.37 s	2.75 s	0.601 s
Time Delay (td)	1.381 s	2.09 s	0.2032 s
Settling Time(ts)	5.97 s	3.35 s	1.168 s
Steady State Error	1.59%	0.065%	0.003%
Overshoot	-	-	**1.327**

4. To maximize the benefits of energy storage in reducing peak power and energy consumption in railways, some researchers (S. Nallaperuma et al., 2021) developed a genetic algorithm-based optimization framework to optimize a DC electric railway network in terms of a comprehensive set of decision variables, including storage size, charging/discharging power limits, schedule, and train/track driving style. Based on the train operating style and peak power reduction, experimental results for the real networks under study revealed a 15% to 30% reduction in energy consumption. Text on energy efficiency. These models were analyzed using basic physics formulas related to motion and energy. Traction, resistance, and gradient forces are the primary determinants of train motion. The complexity of these models varies depending on the number of trains, substations, and the number of cars within the train. In general, a train journey between two locations consists of four operating phases: acceleration, departure, slip, and braking. However, in real life, depending on route gradients, speed limits, and dynamic factors with schedule changes, the actual journey phases can be altered [41].

5. The researcher optimized the proportional-integral derivative of the controller to obtain the best speed regulation for a three-phase BLDC motor using a contemporary heuristic optimization approach (I. Adebayo et al., 2020). To achieve excellent dynamic control performance, a Genetic Algorithm (GA)-based PID controller was used. Using DC electrical machine theory, the mathematical equation for a brushless DC motor—which defines the voltage, rotational angular velocity, and associated torque—was applied. To capture and compare the best speed and torque control characteristics of BLDC motors, the genetic algorithm was further examined using the three common performance indicators of integral time absolute error (ITAE), integral square error (ISE), and integral absolute error (IAE). When compared with the existing ZN-PID controller technology, the simulation result showed that the system equipped with the GA-PID controller has superior system response, as shown in Table 8 [42].

6. To determine the constants of the PID coefficients—the proportional gain, the integral gain, and the derivative gain, the researchers (E. W. Suseno and A. Ma'arif, 2021) adjusted the trial-and-error technique. This idea, which is used to alter the PID coefficients, leads to biological evolution. The Matlab simulation technique is used in this work, and the results are applied to DC motor devices constructed using the Arduino Uno board. Compared to the trial and error method, the evolutionary algorithm methodology yields a system with a lower maximum height and a better constant time. With settling time = 13.5, overshoot = 2, and rising time of 2.7872, the testing procedure produced the best two statements. For mutation 1, the PID coefficient was KP = 3.7500, KI = 1.3184, and KD = 0.2051. With an overshoot value of 2, a settling time of 18, and a rising time of 2.6462, the ideal PID coefficient value at the intersection is 0.4, which translates to KP = 4.2090, KI = 1.2012, and KD = 0.2539. After the investigation and data processing for this study are finished, the following conclusions might be drawn. With a crossover effect of 0.8, a mutation impact of 0.4, and an overshoot of less than 10%, the optimal solution was identified by the genetic algorithm for modifying PID control settings after 100 generations. Furthermore, the impact of the generational count of differences 120 and 150 is also shown in Figure 3, Tables 9, and 10 [43].

Table 8. Controlled system response characteristics for BLDC motor [42]

Controlled system response characteristics for BLDC motor control				Corresponding Kp , Ki and Kd values for BLDC motor	
Tuning technique	Percentage Overshoot	Tr (s)	Ts (s)	Kp	Ki
ZN-PID	21.44	0.51	3.56	107.45	238.37
GA-PID (ITAE)	0.00	0.65	1.82	204.62	189.23
GA-PID (ISE)	3.57	0.61	2.51	196.44	232.33
GA-PID (IAE)	10.71	0.59	2.62	182.74	212.65

Table 9. The Trial and Error Method is used in Testing 1 [43].

PID Controller Parameter						
No.	KP	KI	KD	Tr (s)	Ts (s)	Overshoot
1	1	8	15	1.4440	NaN	85.6825
2	10	25	15	0.8129	NaN	49.2620

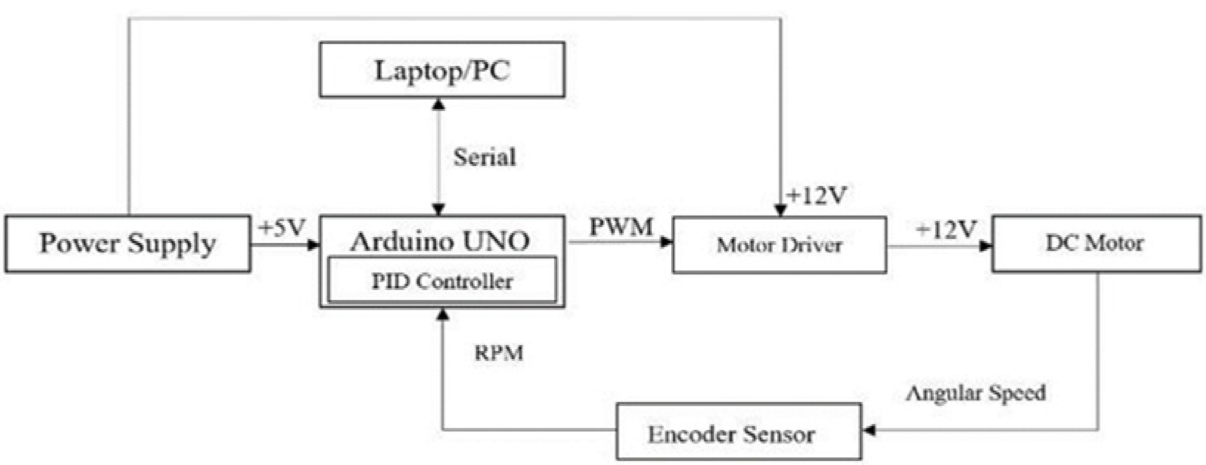

Fig 3. Hardware Block Diagram (DC Motor Speed Control System Using Arduino and PID Controller)[43

Table 10. Genetic Algorithm technique with mutation and cross-over impact [43]

The Genetic Algorithm technique with mutation impact is used in Test 2.										
No.	**Mutation**	**Cross-over**	**Generations**	**Best Fitness**	**KP**	**KI**	**KD**	**Tr (s)**	**Ts (s)**	**Overshoot**
1	0.8	0.6	100	25.1027	7.6270	1.9238	0.2930	0.0813	0.1500	0
2	1	0.6	100	25.6586	3.7500	1.3184	0.2051	0.1288	0.2428	0
Testing 3 uses the GA Method with the crossover Effect										
No.	**Mutation**	**Cross-over**	**Genera-tions**	**Best Fitness**	**KP**	**KI**	**KD**	**Tr (s)**	**Ts (s)**	**Overshoot**
1	0.6	0.2	100	22.6874	1.8750	5.9961	0.0195	0.0746	0.6191	36.1315
2	0.6	0.4	100	25.9547	4.2090	1.2012	0.2539	0.1444	0.2737	0
The GA technique with the impact of the number of generations of variations is used in Testing 4.										
No.	**Mutation**	**Cross-over**	**Genera-tions**	**Best Fitness**	**KP**	**KI**	**KD**	**Tr (s)**	**Ts (s)**	**Overshoot**
1	0.6	0.6	120	23.4426	3.7695	0.5469	0.6152	0.3889	0.7122	0
2	0.6	0.6	150	29.5037	8.6532	0.1855	4.9025	1.2614	2.2480	0
Comparison of PID Parameters for Hardware-Based Testing 1–4										
No.	**Methods**				**KP**	**KI**	**KD**	**Tr (s)**	**Ts (s)**	**Overshoot**
1	**Trial and Error 1**				1	8	15	2.2882	99.800	25
2	**Trial and Error 2**				10	25	15	1.7756	NaN	20
3	**G. A. with Mutation 0.8**				7.6270	1.9238	0.2930	1.3754	42.250	12
4	**G. A. with Mutation 1**				3.7500	1.3184	0.2051	2.7872	13.500	2
5	**G. A. with crossover 0.2**				1.8750	5.9961	0.0195	2.2917	94.250	10
6	**G. A. with crossover 0.4**				4.2090	1.2012	0.2539	2.6462	18.000	2
7	**G. A. with number of Generations 120**				3.7695	0.5469	0.6152	1.3200	24.3333	7
8	**G. A. Influence Number of Generation 150**				8.6532	0.1855	4.9025	3.4228	NaN	15

7. To regulate the speed of a DC motor, the researchers (V. Melnic and I. Cojuhari, 2022) created a fuzzy controller. The outcomes of fine-tuning the controller using the maximum stability approach were contrasted with iterations and genetic algorithms. A computer simulation was used to confirm the effectiveness of the developed fuzzy controller, and the fuzzy controller tuning algorithm was created based on the error and the rate of change of the error signal. This resulted in the closed-loop step response performance results are presented in Table 1 [44].

8. The genetically engineered DC motor was the subject of the study carried out by M. S. Amiri et al. (2020). Kirchhoff's law and the dynamic model of the shafts and gearbox, determine the mathematical model of the DC motor. MATLAB/Simulink first estimates the DC motor parameters based on the values displayed in Table 3.12. In order to reduce the simulated and real angular path error that the encoder records, the estimated parameters are the starting values of the genetic algorithm (GA).

Table 11. Table 11 Performance Automatic Control System [44]

No	Controller	Method	Performance of the system			
			Tr	Ts	σ	λ
1	PID	GA	0.55	2.00	3.99	1
2	PID	MSD	0.93	5.039	7.83	1
3		Fuzzy controller	4.2	4.2	-	-

The DC motor's mathematical model and the best estimated model is verified using various voltages as inputs to the real DC motor. Table 3.13 displays the findings and numerical analysis, which demonstrate that the evolutionary algorithm is appropriate for estimating the parameters of platforms with nonlinear features [45].

Table 12. Table 12 Estimated parameters of a DC motor [45]

Km	Kb	L	R	Jsh	Jr	Br	Bsh
15.422	0.0035	0.0277	0.0021	0.0518	0.1	0.1	0.0035

Table 13. Table 13 Mathematical model, numerical analysis of error [45]

Method	GA		Conventional method	
Voltages	AE	ME	AE	ME
V=3 $\sin(0.5\,\pi t)$	0.0782	0.245	3.3643	6.68
V=5sin (0.5 πt)	0.7299	1.45	6.2678	12.4
V=7sin (0.5 πt)	1.6698	3.06	9.4237	18.5

9. In this research (M. A. Alwan and A. J. M. Al-Furaiji, 2021), the researcher proposed a large-scale design for a speed and load controller for DC motor conversion, based on a proportional integral derivative (PID) controller with a genetic system to adjust the controller parameters. The genetic-based PID controller was simulated using the Matlab software package and tested under various sudden load values and operating speeds. The current control loop contains the proposed PID controller, a pulse width modulation PWM generator, and an H-bridge inverter. With the genetic system optimizing the advanced PID controller parameters, the results show that this module has a significant effect in maintaining the motor speed profiles and output torque after applying a sudden load, as shown in Figure 4, and intensifying the motor performance at various speeds and load conditions.[46]

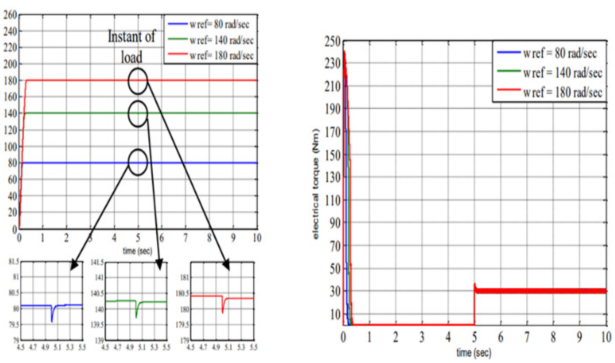

Fig 4. The motor speed and electrical torque profiles at time instant (t = 5 sec) with varying operating speeds (80, 140, and 180 rad/sec) with a sudden load of 30 Nm [46]

10. The researchers (M. T. ÖzdemiR, M. M. Karaca, and A. T. KaraşahiN,2020) discussed the inverted pendulum system which is preferred by many people to examine the performance of control techniques as the inverted pendulum is an engineering problem that is difficult to control due to the nonlinear structure of the system. For the inverted pendulum problem, the equations of motion were derived and expressed in the form of a state space and the design criteria were determined. The design in the inverted pendulum system aims to control the positions of the car and the pendulum as a criterion. The control technique was determined according to these goals and the linear quadratic regulator (LQR) technique was used as a controller. Multiple cases were preferred with the LQR controller in the inverted pendulum system because its variables can be controlled. In the study conducted, the LQR controller improved the Q and R matrices which directly affect the performance using the genetic algorithm. The LQR controller was improved and two different methods were applied as the standard LQR controller. The genetic algorithm, unlike the exhaustive search algorithms, focuses on the best. It may not reach the best because it does not have an approach to achieve it, but it is one of the best algorithms in taking into account the time constraint. It was preferred because it was one of them. In the improvements of the inverted pendulum system, the objective functions are generally modified according to the reference value. It is used as a combination of rise time, settling time and steady state errors. In the study conducted, a different fitness function proposal for the genetic algorithm was presented. This recommendation is based on the reference position value of the car and its value and is designed to minimize the difference between the position values. The fitness function of the genetic algorithm (GA). It has been shown to achieve acceptable results when used with the formula proposed in the study. As a result of the experiments conducted, the LQR controller, optimized using the genetic algorithm, works with the values found by trial and error method. It has been observed that it is more successful than the controller. At the same time, since the Q and R matrices are determined by the genetic algorithm, this prevents wasting time in determining the parameters [47].

3 Optimum Control Strategies

Several methods based on different strategies have been proposed to control the DC motor optimally. Control strategies can be implemented using the indirect optimization approach, such as the analytical approach, and the direct optimization approach, such as linear programming, dynamic programming, and the optimum genetic algorithm [48] and [49].

3.1 PID Control

The Proportional-Integral-Derivative (PID) controller is a robust and widely used control strategy in engineering applications, including control systems. It is distinguished by its effectiveness and simplicity in both theory and simulation outcomes. A PID controller consists of three terms: proportional, integral, and derivative. The proportional term is used to reduce the static error or steady-state error. The integral term is used to reduce the steady-state error and produce a faster system response. The last term is the derivative term [50]. Most control systems in industry use PID controllers because they have unique functions compared to other controllers. They are simple, do not require much time to design, and do not require any core work. The human brain is not perfect and can be inconsistent, but a computer can perform consistently. Therefore, a PID controller is like a brain for an electronic gadget. Once you design the PID parameters for your control system, you do not need to work with it constantly. It automatically works for your outputs. It is the most commonly used controller in Control System Engineering [51]. When a set-point is changed quickly, the PID controller's response to these changes is slow. This happens because the proportional term primarily controls the system response, as kP is significantly higher than kI and kD. The system response depends on the value of the controller parameters (Proportional, Integral & Derivative Values). There are much faster response systems designed using only controllers like neural networks (NN), fuzzy logic controllers (FLC), etc. They are used because they provide a much faster response for the system and maintain system stability using fewer controller gains compared to systems that use Classical PID Controllers [52]. As shown in Figure 5.

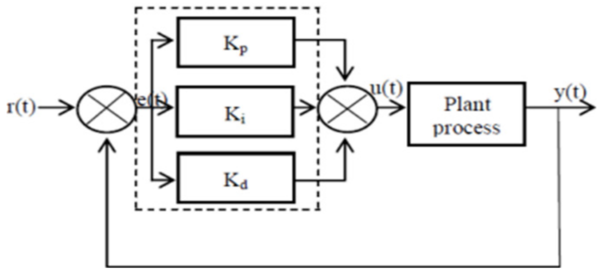

Fig 5. Block diagram of a PID control system

3.2 Optimal Control Theory

By recommending optimal connections between system states and practices that are subject to a number of constraints, optimal control theory is used to create suitable system states. If this is achieved, a dynamic system can offer excellent performance. The optimal control law or policy created by optimal control theory is enacted as a means of providing a state feedback control law for performance improvement. It integrates the state feedback method's advantages with fundamental optimization strategies. In most cases, the optimal control law provided by optimal control theory is provisional [53]. The optimal supervisor must recalculate the optimal control law's coefficients on a routine basis to reflect load alterations or alterations in other categories of procedures. Genetic algorithms have the ability to manipulate continuous and discrete parameters, and the capability to deal with multiple variables are some of their unique features. The genetic algorithm affects an object paradigm, that is, the fittest individuals will live on, in analogy to selection. The individuals who are to be manipulated are chosen through controlled or random training, which is comparable to breeding in nature. It has also been demonstrated that the algorithm is a successful approach for optimizing functions that are difficult to solve. Genetic algorithm is utilized as an optimization technique in this investigation [54].

3.3 Genetic Algorithm Optimization

Genetic algorithm is a major component of computational techniques. This technique is used to optimize different parameters of a system. The full potential of this technique can be utilized if the dimensions of the optimization problem are large or the parameters of the system to be optimized are interconnected, or the function of the system is multi-modal. Genetic algorithms use the principle of evolution to carry out the optimization process. In evolution, the fittest organisms survive. The genetic algorithms will work similarly. The quality of the solution in genetic algorithms is the fitness of an individual. The individuals are the solutions represented in the form of strings. At the start of genetic algorithms, a new generation of individuals is created from the parents which have good fitness. The offspring has mutations in it and starts to form new generations [55]. Two major issues will be discussed in this paper: 1) the optimization using the powerful technique of genetic algorithms, and 2) the application of genetic algorithm to control the DC motor. A genetically based search and optimization method is called a genetic algorithm (GA). Essentially, solutions representing potential designs are measured according to their "fitness." The fittest designs are then selected and modified to produce the next generation. This selection and modification process continues until a termination condition is met. The genetic algorithm first generates a random population of individuals. Each individual represents a specific design. The elements in the design, which may also be called genes, are independent variables defining the design. All individuals are evaluated with an objective function. The genetic algorithm uses a fitness function to evaluate each individual and assign a value of fitness to it. The fitness of each individual represents how good a solution the individual represents. The evaluation process is repeated for every individual in the population to find the fitness of each [56].

3.3.1 Encoding Schemes

In genetic algorithm optimization, encoding is the representation and manipulation of possible solutions in a form which allows the variation and natural selection processes of GA to operate. Valid encoding schemes allow the search to be performed systematically, and are an important consideration during any optimization process. A wide variety of encoding approaches have been developed. A considerable part of current methodology in the genetic algorithm approach to optimization involves the development of encoding schemes suitable for representation of particular candidate solution (string) structures. Various encoding techniques in genetic algorithm can be found in the literature. For example, binary encoding where string represents binary numbers, and Gray encoding where binary number is converted into the binary-reflected Gray code [57]. Encoding schemes have been widely employed for optimization of control strategies in DC motor systems. It represents state vector (s) as discrete-time representation (sampling period τ) according to (17). However, we have chosen a treasury of features to construct the controller, for example, to jointly provide and optimize the proper control regime in cyber-physical systems with variable elements, as well as jointly optimize the control of actuators (encoded through the control table). Taking into account the variety of types of AC motors and the number of control parameters, the control table we opted for in this context was chosen for its simplicity and optimization. The control table values provide the logical intuitions writers in terms of desired direction, and are held constant to ensure the convergence toward the optimal control, which counteract the influence of various random noise factors affecting the motor current [58].

3.3.2 Fitness Functions

The main part of the genetic algorithm optimization of a present problem is the way of the definition of fitness functions. The purpose of the definition of the fitness function is the estimation of the quality of an individual of the population. The definition of the fitness function must encourage the evolution towards the best possible solution. The way of defining the fitness function depends on the surface of the solution. The genetic algorithm optimization is very sensitive to fitness functions. The difficulty is to find a formula that delivers good convergence, knowing that a fitness function is defined once (at the early simulation stage) and is not updated throughout optimization. A good fitness function should take into consideration the objectives of the solution, the constraints, and the possible range of solutions. The adoption of "soft constraints" is also a quality of a good fitness function since it reduces the search space and the time of the genetic algorithm optimization procedure [59] and [60] The fitness function should be defined in such a manner as to be the reflection of the objective function that must be minimized (or maximized) and of the constraints that must be satisfied by a certain solution. Thus, it is rather clear to say that a fitness function represents a measure for how far the individuals of the given population are from the optimum or from satisfying the constraints. Further, the value of the fitness function influences the evolution of the individuals or, in other words, the concentration rate should be a function of the solution's classic value. The genetic algorithm is capable of using the relationships which already exist in one or another manner [61] and [62].

4 Challenges and Future Directions

While an optimal control scheme seems to be appealing, there are some challenges and potential complex issues associated with the process of using such techniques in a real-time domain. A requirement of complete knowledge of the system state and uncertainty of the system model response and change of parameters during control system design due to aging of the DC motor or some other uncertainties like change of load inertia, abrupt change in input voltage, and mutations, make these methods impractical. Another challenge with using optimum control strategies, particularly for DC motor systems, is that they are highly non-linear in nature, which results in difficulties when converting these systems into state space form. This is because it is often difficult to get a reasonably accurate model with reasonable convergence. In most control techniques, the required change of direction of the actuated system or system load changes, such as that which can occur in a commercial hard disk drive (HDD), leading to a power-on suggested tau value that is non-physical. This requires some additional time-consuming steps to be carried out before control can be reinstated. Furthermore, this seemingly simple problem becomes convoluted with an additional electrical disturbance, such as RFI/EMI on the actuator, or an adjustment to the required performance, causing the problem to get worse [63]. The development of new methods to be able to deal with such problems needs to be developed. As it is widely known, DC motors are very efficient in most drive applications. However, the requirement of an accurate and high-performance controller is much needed. Sustained research needs to be directed to finding new and efficient control techniques that improve the level of the feed-forward control to drive the system and to give the information to the controller setup for the system as a stable system. Finally, instead of using extensive techniques or getting a model directly from the system, some mathematical techniques can be used to get the model. This model will represent the characteristics of the given system. A model-based technique will be developed to use this obtained model. Also, some more sophisticated and advanced methods can be developed for an adaptive system.

4.1 Challenges in Implementing Optimum Control Strategies

In the last two decades, numerous research works have been published relating to the control of electrical motors. The different control methods used, along with their optimum strategies, are available to make the performance of the motor more reliable. The use of these strategies makes the performance of the motor excellent, and the control process performed in this manner is also economical. However, the use of an optimum strategy in the control system increases the hardware complexity. The simulation model of the control system has to be created to determine the optimum parameters and identify the system. Implementing an optimum control strategy becomes a challenging task due to the above problems [64].

4.2 Controller Design

The output model selects a suitable controller. The tuning of the controller in the continuous domain is done using techniques such as genetic algorithm and particle swarm optimization. The obtained controller is then converted into the discrete domain by following the model-based optimization. The design of a controller is done using these methods and then tested with torque or speed transients. Four types of disturbances are also applied in the system [65].

4.3 Future Research Directions

In spite of intensive research regarding the implementation of optimum control strategies for the DC motor system, it seems that there are still many problems to investigate. Hence, for the near future, the following studies should be given some attention. The optimization of control strategies for robotic systems presents a promising research approach that may be further developed. Therefore, finding a DC motor's model, its control issues, and eventual optimization is also an inviting novel step. Optimum control of electric drives that are powered by alternative energy sources such as wind or solar power systems is another promising research direction. The existing drives are controlled in such a way that they prime the motor to have maximum power from alternative energy sources. There is no doubt that this research direction carries the weight of the future as the energy source is a life source. Designing accurate motor drives with the application of sophisticated control systems is currently a principal research interest. It is important to investigate novel drive control systems that could be operated using Motorsymb (a symbolic computing environment for electromagnetic design). Even though reference exists for investigation of optimal control of this novel approach, a detailed investigation to maximize the capabilities and identify underlying methods is an inviting research step. Inverse problems are also interesting because motor drives are nothing but intended solutions for the designed structures. Hence, how effectively the designed structures help in vibrant applications is another research direction that could be addressed. Investigations of speed control and current control designs are also inviting research issues. The existing methods use efficiency minimization as an objective function, and most of the functions are dual-endedly formulated.

5 Conclusions

In this paper, the idea of effective use of genetic algorithm to design an efficient control strategy from the perspective of optimal control is proposed. The feedback controller, as a design strategy, plays a vital role in controlling any electrically driven system. The driving mechanism of the system may offer different options, but all the factors will converge in controlling the motor or driver mechanism. Due to the highly interconnected whole driving principle. The basic and most important goal of the research is to get the optimum value of the useful parameters in the electrical system; however. The latest emerging controller design technique is to design the optimum value of the parameters using soft computing techniques. This research is mainly based on the optimization work of DC motor by applying genetic algorithm in real-time applications for efficient or optimal control of DC motor system. The inversion of small-scale DC motor is very popular nowadays, especially in the purposes of robotics and control system. From the detailed and insightful research, it can be concluded that some of the following situations have consumed the application and soft simulation. It may be said that the research work will give high-quality and effective results. The application of genetic algorithm to control DC motor system from the perspective of multi-factor optimization may help to outsource a number of different applications. With all the detailed study, it is known that it can be used to achieve the highest efficiency in the current system. At the same time, this theoretical and experimental transfer may give the highest efficiency of multiple parameters and provide good results.

Declaration of conflicting interests

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author Contributions

Conceptualization, Thamir Hassan Atyia; Methodology, Suhail; Software, Suhail Mahmoud Abdullah; Validation, Suhail Mahmoud Abdullah and Thamir Hassan Atyia; Resources, Suhail Mahmoud Abdullah and Thamir Hassan Atyia; Data Curation, Suhail Mahmoud Abdullah; Writing original draft preparation, Suhail Mahmoud Abdullah; Writing review and editing, Suhail Mahmoud Abdullah and Thamir Hassan Atyia, Supervision, Thamir Hassan Atyia, Project Administration, Suhail Mahmoud Abdullah.

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Declaration of generative AI and AI-assisted technologies

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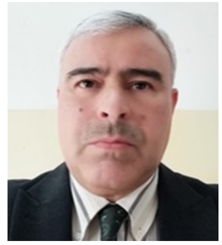
Biography



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