АҚПАРАТТЫҚ-КОММУНИКАЦИЯЛЫҚ ТЕХНОЛОГИЯЛАР / ИНФОРМАЦИОННО-КОММУНИКАЦИОННЫЕ ТЕХНОЛОГИИ / INFORMATION AND COMMUNICATION TECHNOLOGIES

DOI 10.54596/2958-0048-2025-1-207-214
UDK 004.89
IRSTI 34.23.01

ANALYSIS OF THE IMPACT OF GENETIC ALGORITHM PARAMETERS ON OPTIMIZATION EFFICIENCY IN MATLAB

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Abstract

This paper presents an analysis of the impact of genetic algorithm (GA) parameters on the efficiency of optimizing complex nonlinear functions using the MATLAB Optimization Toolbox. The study focuses on the Rastrigin function, known for its complex structure and multiple local minima. Key GA parameters, including population size, mutation and crossover probabilities, and stopping conditions, are considered. Experimental results demonstrate that proper parameter tuning significantly enhances the algorithm's ability to find the global minimum while reducing the likelihood of premature convergence. The findings highlight the importance of adapting GA parameters to specific optimization tasks and demonstrate the potential of GA applications in engineering and scientific domains. Limitations of the method are discussed, and future research directions, including the development of hybrid approaches, are proposed.

Keywords: genetic algorithms, optimization, algorithm parameters, MATLAB, Rastrigin function, global minimum, nonlinear functions, hybrid optimization.

MATLAB ОРТАСЫНДАҒЫ ОҢТАЙЛАНДЫРУ ТИІМДІЛІГІНЕ ГЕНЕТИКАЛЫҚ АЛГОРИТМ ПАРАМЕТРЛЕРІНІҢ ӘСЕРІН ТАЛДАУ

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Аңдапта

Мақалада MATLAB Optimization Toolbox көмегімен күрделі сызықтық емес функцияларды оңтайландыру тиімділігіне генетикалық алгоритм (ГА) параметрлерінің әсерін талдау ұсынылған. Зерттеу нысаны ретінде күрделі құрылымымен және көптеген жергілікті минимумдарымен танымал Растригин функциясы таңдалды. Га-ның негізгі параметрлері, соның ішінде популяция мөлшері, мутация және кроссовер ықтималдығы және тоқтату шарттары қарастырылады. Жүргізілген эксперименттер алгоритмнің параметрлерін дұрыс реттеу оның ғаламдық минимумды табу қабілетін едәуір арттыратынын және мерзімінен бұрын конвергенция ықтималдығын төмендететінін көрсетті. Нәтижелер параметрлерді нақты міндеттерге бейімдеудің маңыздылығын көрсетеді және инженерлік және ғылыми қосымшаларда ГА қолдану әлеуетін көрсетеді. Қорытындыда әдістің шектеулері талқыланады және гибридті тәсілдерді әзірлеуді қоса алғанда, қосымша зерттеулерге бағыттар ұсынылады.

Кілт сөздер: генетикалық Алгоритмдер, оңтайландыру, алгоритм параметрлері, MATLAB, Растригин функциясы.

АНАЛИЗ ВЛИЯНИЯ ПАРАМЕТРОВ ГЕНЕТИЧЕСКИХ АЛГОРИТМОВ НА ЭФФЕКТИВНОСТЬ ОПТИМИЗАЦИИ В СРЕДЕ MATLAB

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Аннотация

В статье представлен анализ влияния параметров генетических алгоритмов (ГА) на эффективность оптимизации сложных нелинейных функций с использованием MATLAB Optimization Toolbox. В качестве объекта исследования выбрана функция Растригина, известная своей сложной структурой и множеством локальных минимумов. Рассматриваются ключевые параметры ГА, включая размер популяции, вероятность мутации и кроссовера, а также условия остановки. Проведенные эксперименты показали, что корректная настройка параметров алгоритма значительно повышает его способность к нахождению глобального минимума и снижает вероятность преждевременной сходимости. Полученные результаты подчеркивают важность адаптации параметров под конкретные задачи и демонстрируют потенциал применения ГА в инженерных и научных приложениях. В заключении обсуждаются ограничения метода и предлагаются направления для дальнейших исследований, включая разработку гибридных подходов.

Ключевые слова: генетические алгоритмы, оптимизация, параметры алгоритма, MATLAB, функция Растригина.

Introduction

Optimization is one of the fundamental tasks in various fields of science and engineering, including the design of complex systems, data processing, and process control. Modern optimization methods aim to address nonlinearity, multimodality, and high dimensionality of problems, making them a critical focus of research in artificial intelligence. Genetic algorithms (GAs), which mimic the processes of natural selection and evolution, are among the most effective approaches for solving such problems.

The relevance of this research lies in the broad applicability of GAs. In recent years, there has been growing interest in using GAs to solve optimization problems in complex nonlinear systems. For instance, studies [1-4] emphasize the effectiveness of GAs in engineering applications such as aerospace design and optimization of energy system parameters. At the same time, [5] highlights the insufficient exploration of the impact of algorithm parameters on performance, opening opportunities for their adaptation to specific tasks. This study addresses the optimization of the Rastrigin function, a standard test case for optimization algorithms due to its multiple local minima.

The objective of this study is to investigate the methodology for applying genetic algorithms to minimize complex multimodal functions using MATLAB.

To achieve this objective, the following tasks were defined:

- Examine the features of applying GAs to nonlinear function optimization.
- Develop a procedure for tuning GA parameters in MATLAB.
- Visualize the target function for preliminary analysis.
- Conduct computational experiments to minimize the Rastrigin function.
- Evaluate the efficiency and reproducibility of results obtained using GAs.

The scientific novelty of this study lies in applying GAs for analyzing a complex multimodal function using MATLAB Optimization Toolbox and investigating the influence of algorithm parameters on accuracy and convergence speed. The proposed approach can be adapted to a wide range of applied tasks.

The significance of the study is that the developed methodology effectively identifies global extrema of nonlinear functions, which can be valuable for engineering system design, machine learning, and data processing. Moreover, the proposed approaches and results can be utilized for teaching optimization methods in educational institutions.

Thus, this research contributes to the development of optimization methods by providing a tool for efficiently solving problems in complex function landscapes.

Research methods

The methodology of the study was based on the use of MATLAB and its Optimization Toolbox to implement genetic algorithms. The main stages included the following:

1. Defining the optimization function. At this stage, the Rastrigin function was selected as the target function. It is a multimodal function, making it a valuable benchmark for testing optimization algorithms. To analyze the landscape of the function, a 3D plot was generated using the mesh command, and a contour plot with level lines was created using the contour command.
2. Algorithm preparation. A fitness function was created in the form of a MATLAB file, @myfun, to implement the target function with a focus on minimization. The boundaries of variable changes were established to constrain the search space.
3. Tuning GA parameters. The MATLAB Optimization Toolbox graphical interface was used to perform this step. The following configurations were applied:
   - Setting the initial population with randomly distributed chromosomes;
   - Defining crossover, mutation, and selection operators to process the population;
   - Configuring stopping criteria, including specifying the average change in the function value as the termination condition.
4. Optimization execution. The algorithm was launched using the gatool command, and results were monitored through built-in visualization tools. Parameters such as population size, crossover probability, and mutation probability were investigated during the GA execution.
5. Efficiency evaluation. To analyze the reproducibility of the experiment, the states of the random number generator were fixed. Additional visualization settings were enabled to display the progress of the optimization process.
6. Post-processing results. Data on the minimal values of the function and the corresponding parameters at which they were achieved were collected. A comparative analysis of the influence of algorithm parameters on its performance was conducted.

The research methods ensured the completion of the defined tasks and provided substantiated results that confirm the effectiveness of genetic algorithms for solving optimization problems.

Research results

Nonlinear functions often pose challenges for optimization algorithms due to their complex mathematical descriptions and the presence of numerous local extrema. The Rastrigin function serves as an example of a standard benchmark for evaluating the effectiveness of optimization methods. Genetic algorithms (GAs) efficiently explore such functions through a population-based approach, which enables simultaneous investigation of multiple regions in the solution space. This provides GAs with an advantage over classical methods, such as gradient descent, which are prone to getting trapped in local minima.

The working principle of GAs is based on processes that simulate natural selection, genetic recombination, and mutation. This approach ensures gradual improvement in the population of solutions with each iteration. The evolutionary nature of the algorithm makes it suitable for problems with nonlinear dependencies between variables, where analytical methods often fail. Furthermore, GAs do not require the computation of derivatives, which is particularly important when optimizing functions with discontinuities or unknown mathematical structures.

A key feature of GAs is their flexibility in parameter configuration. Users can tailor algorithm parameters, such as population size, mutation probability, and crossover type, to meet specific problem requirements. This adaptability allows GAs to efficiently handle functions that traditionally demand significant computational resources or analytical transformations [6]. However, the stochastic nature of GAs introduces variability in results, necessitating multiple runs to ensure reliability. This observation aligns with prior experiences in solving engineering and data analysis problems.

MATLAB provides robust tools for implementing GAs. The use of the Optimization Toolbox enables the definition of complex functions, the establishment of constraints, and control over the optimization process through graphical visualization. These features simplify parameter configuration and experiment execution [7]. The application of GAs in MATLAB was exemplified by the study of the Rastrigin function. The algorithm successfully identified the global minimum of this multimodal function, confirming its effectiveness for highly nonlinear optimization tasks. During the experiments, it was observed that GAs not only avoid local minima but also produce reproducible results when the state of the random number generator is fixed.

A key objective of the research was to develop a procedure for tuning GA parameters in MATLAB. This stage involved identifying the critical parameters affecting GA performance and configuring them using the Optimization Toolbox interface. The tuning process was conducted according to the plan presented in Table 1.

Table 1. Procedure for Tuning GA Parameters in MATLAB

No.	Stage Name	Stage Description
1	Selecting the initial population	The population size was specified in the Population Size section, determining the total number of chromosomes in the algorithm.
2	Defining selection, crossover, and mutation operators	Crossover and mutation operators were chosen from the options available in MATLAB. A block method was used for crossover, ensuring uniform gene distribution from parent chromosomes.
3	Setting stopping conditions	Stopping conditions included a minimal change in the fitness function value during the last iterations..
4	Defining variable boundaries	Boundaries for variables were specified in the Constraints panel. These limits corresponded to the domain of the Rastrigin function.
5	Configuring visualization	Graphs displaying the change in the objective function value over iterations were enabled to monitor algorithm performance. These graphs allowed tracking the algorithm's progress toward the optimal solution.

The research results demonstrate the application of genetic algorithms for optimizing the multimodal Rastrigin function. At the initial stage, the function was visualized, allowing for an analysis of its complex landscape and confirming the relevance of the chosen method.

The 3D plot of the Rastrigin function (Figure 1) clearly illustrates the presence of multiple local minima, which is characteristic of multimodal functions. The graph distinctly shows deep valleys corresponding to the function's minimum values and peaks representing regions of maxima.

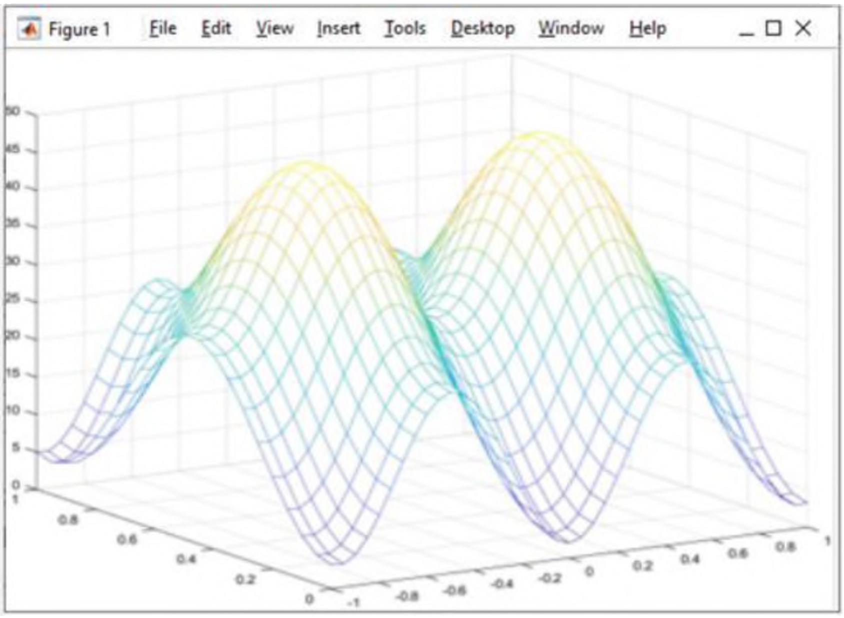

Figure 1. 3D plot of the complex function surface

The analysis of the contour plot (Figure 2) allowed for a more precise identification of these regions, where the purple zones represent global minima and the yellow zones indicate maxima. The contour plot was additionally used for the preliminary assessment of the search area.

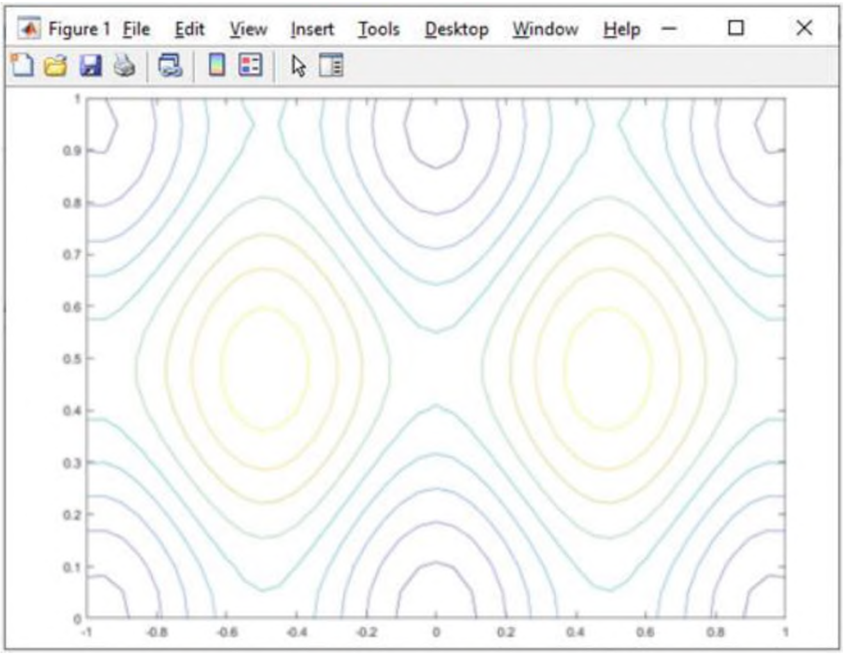

Figure 2. Contour plot of the function

The Rastrigin function was defined as the target function in the form of a MATLAB script as follows (Equation 1):

$$f(x,y) = 25 + (1.1x^2 - 11\cos(2.05\pi x)) + (1.2y^2 - 12\cos(2.1\pi y) \quad (1)$$

The optimization was performed within the range of variable values *x* and *y* from -5 to 5. The genetic algorithm was executed using the built-in Optimization Toolbox, where algorithm parameters such as initial population size, mutation probability, and crossover probability were set according to MATLAB's default settings. The optimization process was monitored through visualization of the objective function values across iterations.

Figure 3 presents the results of the function optimization. The minimal function value was achieved at the point 2.2476, corresponding to the theoretical global minimum.

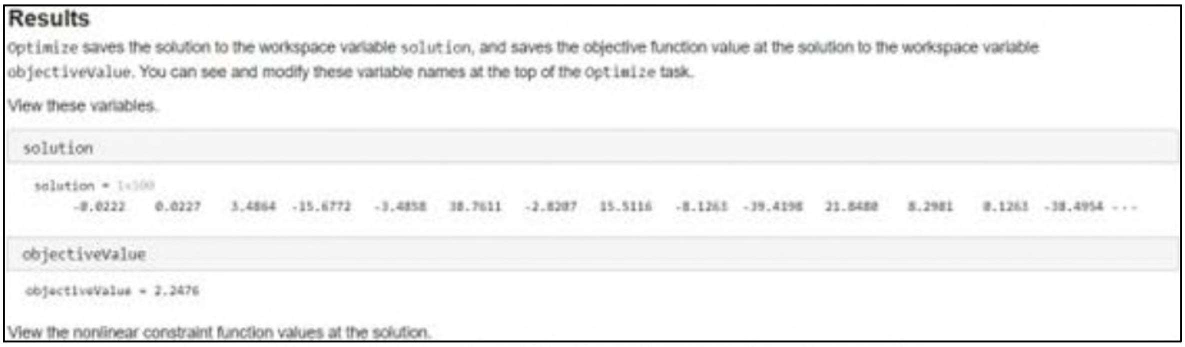

Figure 3. Results of the function minimum search

Figure 4 illustrates the configuration of the variable boundaries for the function.

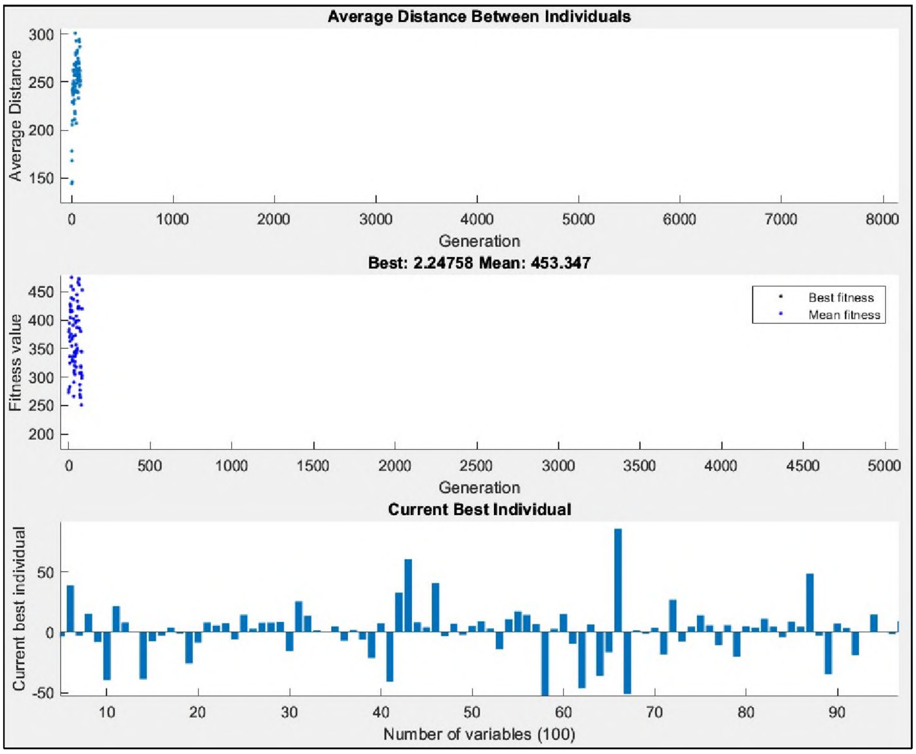

Figure 4. Configuration of variable boundaries for the function

When configuring the GA parameters, the primary population parameters were kept at their default settings, including scaling, selection, and stopping criteria. The analysis of the optimization process revealed that the algorithm approached the global minimum region within the first 50 iterations, despite the presence of numerous local minima. The final results at the

100th iteration confirmed the high efficiency of the algorithm's configuration. Additionally, the average change in function values during the last iterations was less than the stopping threshold, set at 10^{-6}.

One of the key characteristics of the genetic algorithm is its stochastic nature. To ensure the reproducibility of results, fixed states of the random number generator were used. Repeated runs of the algorithm confirmed the stability of the obtained results.

The findings of the study demonstrated that the genetic algorithm implemented in MATLAB is highly effective at identifying the global minimum of a complex multimodal function. This approach can be recommended for solving a wide range of optimization problems where the algorithm's adaptability and resistance to local minima are critical.

Discussion

The results of the study confirmed the high efficiency of genetic algorithms for solving nonlinear optimization problems. The application of GAs successfully minimized the Rastrigin function, demonstrating the algorithm's ability to avoid local minima and find a global solution. This outcome supports the hypothesis that genetic algorithms are a powerful tool for working with multimodal functions, where traditional methods such as gradient descent or Newton's method may prove ineffective.

A key focus of the study was the analysis of the impact of GA parameters on the optimization process. It was found that population size, mutation probability, and stopping criteria play a critical role in the algorithm's convergence. For instance, an excessively high mutation probability increases randomness in solutions and reduces search efficiency, whereas too low a mutation probability can lead to premature convergence. Configuring the algorithm parameters using MATLAB Optimization Toolbox proved to be intuitive and allowed process optimization without significant time expenditure.

Among the limitations, the stochastic nature of GAs stands out, resulting in variability in outcomes. To ensure reproducibility, the state of the random number generator must be fixed, a practice successfully implemented in this study. Additionally, the computational complexity of the algorithm increases with the dimensionality of the solution space, highlighting the need for further research on reducing computational costs.

The practical significance of the findings lies in the potential application of GAs for solving real-world problems in engineering, data processing, and machine learning. This method can be utilized for designing complex systems that require optimal parameter search under numerous constraints and high nonlinearity.

Future research could focus on the development of hybrid algorithms that combine the genetic approach with other optimization methods, such as particle swarm optimization or machine learning techniques. This would improve convergence and reduce computational costs when working with high-dimensional functions.

Conclusion

This study explored the methodology for applying genetic algorithms to optimize complex nonlinear functions using MATLAB Optimization Toolbox. The primary focus was on the Rastrigin function, a standard benchmark for evaluating the effectiveness of optimization methods. The genetic algorithm successfully minimized the function, achieving the global minimum, which confirmed its high efficiency.

The research objectives were accomplished. The study examined the features of applying GAs, developed a procedure for parameter tuning, visualized the target function, and analyzed the obtained results. Parameter tuning, including population size, mutation probability, and stopping criteria, proved to be a key factor in the successful search for the optimal solution.

The scientific novelty of the study lies in the application of genetic algorithms for analyzing complex nonlinear functions and the development of a methodology for their configuration in MATLAB. The results have practical significance, as the proposed approach can be adapted to solve a wide range of engineering and scientific problems.

Thus, genetic algorithms have demonstrated their efficiency and versatility in optimization tasks. Future work is suggested to focus on the development of hybrid algorithms and their application to high-dimensional functions, which will open new opportunities in the fields of optimization and artificial intelligence.

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