

**Enhancing Performance of Intelligent Systems with Genetic Algorithm
Optimization**

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Abstract

Genetic Algorithms (GAs) are popular in optimization of intelligent systems which act in complex dynamic environments. Nevertheless, most of the available GA-based solutions continue to have problems with high cost of computations, early convergence and lack of scalability in practical settings. This study will derive and test a simplified effective GA-based optimisation framework with performance improvement in an AI environment using only one benchmark dataset. The paper is based on recent research on modified and improved GAs in circuit optimisation, distribution network, data mining as well as intrusion detection systems. An experimental design will be implemented, based on software, and in Python; it will make use of the UNSW-NB15 cybersecurity dataset and simple machine-learning classifiers to test GA-based feature selection. Two variants of GA will be applied and compared, a standard and enhanced GA having adaptive mutation. The desired results are expected to be higher precision, quicker convergence, fewer features, and a convenient system that can be replicated and extended with ease in intelligent systems that use AI.

Keywords:

1. Genetic Algorithms (GA)
2. Feature Selection
3. Artificial Intelligence (AI)
4. Intrusion Detection Systems (IDS)

Chapter 1: Research overview

Introduction

The swift growth of intelligent systems, including robotics, cybersecurity, distributed energy management, and data-driven decision platforms, has produced an increased need to apply optimization methods with high robustness that can make use of complex and high-dimensional problems. The idea of Genetic Algorithms (GAs) which is based on the evolution in nature has become one of the most effective population-based search techniques to these applications. Their capability of escaping premature convergence and effectively search large search spaces has been proven to be strong. As an example, Zemliak (2022) demonstrated that the combination of a control vector inserted into the genetic structure leads to the improved accuracy of convergence by several orders of magnitude and a decrease in CPU time by several orders of magnitude. On the same note, Kahouli et al. (2021) established that the optimization of power distribution networks with GA enhances their reliability and minimizes losses of energy subjected to various operational constraints. Moreover, Shi (2020) tackled the efficiency of better GA operators on high-dimensional data-mining processes, whereas Halim et al. (2021) showed that a feature-selection model using GA can reach up to 99.80% accuracy in intrusion-detection.

All these studies point to the fact that GAs (Particularly in their modified or hybrid varieties) provide significant performance improvements in intelligent systems. Nevertheless, there are still issues with the cost of computation, scalability and generalizability. The current study will thus attempt to develop, deploy, and test a better GA-based optimization platform that can be applicable to various AI-driven fields.

Background

The nature of genetic algorithms is evolutionary; they are typified by selection, crossover, mutation; and they replicate biological evolution to incrementally make solutions more optimal. Their ability to trade between exploration and exploitation is what makes them especially useful to AI-based systems, which need to be optimized with uncertainty, nonlinearity, or multi-objective requirements. However, classical GAs are characterized by a number of weaknesses including

slowness in converging, local minima, and parameter sensitivity. This has encouraged scholars to suggest more adaptive, efficient, or hybrid GA models that incorporate AI ideas, evolving fitness functions, and problem-related chromosome models.

To solve these problems, researchers have suggested changes to the fitness functions, chromosome structures and genetic operators. The control vector mechanism, introduced by Zemliak (2022) redefines the fitness function dynamically, resulting in more accurate and fast convergence in circuit optimisation. Kahouli et al. (2021) utilised GA and PSO in power distribution networks to reduce the amount of energy not served and losses of power, which is the strength of GA in multi-objective optimisation. Shi (2020) enhanced the GA operators in large-scale data-mining tasks which has shown a higher capacity to handle high-dimensional data. Halim et al. (2021) integrated GA and intrusion-detection measures into the process of creating an effective feature-selection tool.

These articles indicate that even a few targeted modifications to GA design, as opposed to excessive complexity hybrids, can provide a significant performance benefit, and this is the concept at the heart of the simplistic framework of this project.

Problem Statement

Optimization techniques are increasingly being applied in intelligent systems like robotics, real time scheduler and automated control systems to operate effectively in complex environments that are dynamic. Nevertheless, some of these systems continue to encounter issues of poor allocation of tasks, low flexibility, high cost of calculation and poor scalability. These problems lower the performance of the system particularly in cases that involve real-time or multi objective work.

Genetic Algorithms (GAs) have increasingly become an encouraging solution due to their evolutionary search algorithms that make them more accurate and strong in optimization. Recent research indicates that GAs have the capability of enhancing the performance of systems to a great extent. Indicatively, more advanced models of GA have managed to reasonably accelerate the computation and improve the planning of multi-robot systems (Chabane & Guenounou, 2025). Likewise, scheduling methods that are based on GA have demonstrated greater reliability

and less response time in multiprocessor systems (Hassan et al., 2025). A hybrid between GA-AI models have also enhanced the convergence and design efficiency in intelligent engineering applications (Sun & Sun, 2025).

Although these are the advantages, there are still a number of constraints. Most of the GA solutions are only validated in simulation studies decreasing their practical application. There are models which are very demanding in terms of computation resources and therefore cannot be used on resource constrained systems. Also, the current methods are usually developed to cover specific areas with little applicability to various applications of intelligent systems.

Thus, there is an evident necessity to conduct a study that would help to understand how GA optimization could be further developed and adjusted to enhance the performance, scalability, and applicability in the real-life settings of intelligent systems. Sealing the gap will help in creating more efficient, flexible and adaptive next generation intelligent technologies.

Research objectives

Primary Objective

To explore and increase the efficiency of genetic algorithm optimization methods in the better performance, flexibility, and scalability of intelligent systems.

Specific Objectives

- To examine the problematics and shortcomings of the current optimization approaches applied to smart systems.
- To assess the effectiveness, flexibility, and improvement of performance the different GA-based optimization models that have been reported in current literature.
- To develop an optimal GA-based system that cuts down on the existing constraints of the system namely high computational cost, domain specificity and scalability.
- To present the conceptual or applied solution explaining why an improved GA optimization solution can be applied to perform intelligent systems in various fields.
- To make a comparison of the suggested GA-based solution to the existing optimization methods to identify the relative effectiveness of the first.

Research Scope

The proposed study is aimed at assessing and refining the Genetic Algorithm-based optimization methods in the area of artificial intelligence, and a single benchmark dataset (UNSW-NB15) of intrusion detection is used. The experiment is restricted to software-based experiments which are run on Python, and does not attempt to add hardware hardware or deployment to a real-time system. It is only limited to 2 GA variants, a baseline GA to select features and an adapted GA with adaptive mutation. They are evaluated by a basic machine-learning classifier (Logistic Regression) in the research to make it easy to implement.

The most essential performance criteria are the classification accuracy, convergence behaviour, feature-reduction capability, and computational efficiency. The paper is not set out to create a complete intrusion-detection system but instead, to examine the performance of GA-based optimisation in artificial intelligence problems. Results will be presented as a generalisable framework, which can be applied in other applications of intelligent systems in future studies.

Chapter 2 : Literature review

Literature review

This study addresses the topic of genetic algorithm (GA) optimization to improve the functionality and flexibility of intelligent systems. An overview of six peer-reviewed articles in 2022-2025 gives a profound insight into existing methods, applications, and issues related to this sphere.

Chabane & Guenounou (2025) proposed the initial research named two-stage enhanced genetic algorithm (EGA) which is intended to designate the optimal task allocation and planning in heterogeneous multi-robot systems. The suggested EGA is designed by using domain-specific chromosome encoding of the capability constrained task allocation at the first stage, and the local route refinement at the second stage to reduce traveling distances and enhance load balancing. Compared to other common optimization frameworks such as: Mixed Integer Linear Programming (MILP), Particle Swarm Optimization (PSO), and common single-phase GA, the EGA was found to obtain nearly optimal outcomes with an average optimality gap of less than 1.5 per cent and lower computational times of up to 90 per cent. This scalability indicates the complexity and real-time industrialization of GA. The possibility of a dual-phase design makes the study a considerable strength of the methodology since it gives the study the balance between global search and local optimization, but the study is also limited due to the use of simulation but not the physical validation to generalize the study results. However, it provides a strong background on how GAs may be incorporated in robotic coordination and intelligent automation scenarios.

Naaman et al (2025). gives a summary of the GA techniques and the general application of optimization. The authors present GAs as models of biological evolution that make computations with the assistance of selection, cross-over, and mutation. The survey is in diverse areas of knowledge, and it shows the diversity of GAs in addressing complex optimization problems in machine learning, visual analytics, and robotics. The general value of the work is the generalization of all the variety of GA deployments with the emphasis put on their effectiveness in large and disorderly search spaces. It is however, strictly conceptual and therefore, it is not experimentally tested meaning that it is a bit less applicable. Despite this drawback, it provides a

reasonable theoretical framework on the basis of which the processes of GA will be investigated and introduced into the intelligent system to make it streamline operations.

Tomforde (2023) discusses the functions of GAs to enhance innovation and efficiency of optimization of technologies. The paper highlights the importance of natural evolution imitation by GAs to adapt to more complicated problem solving task in realms of software engineering, robotics and electronic circuit design. Speaking of the key problems including computational intensity and parameter optimization, Tomforde highlights the advantages of GAs when it comes to finding the best solutions. Though the study does not give a quantitative data and empirical results, it offers a valuable conceptual insight of how GA frameworks drive innovation and agility in the intelligent technology design approach. It contributes to the rest of the papers in the sense that it bridges the gap between the theoretical knowledge and cross-domain utility by emphasizing on GAs as the key tools of technological transformation and simplification.

Hassan et al (2025). concerned with scheduling the tasks in multiprocessor real-time systems with the use of a new GA based method. The algorithm was compared to three classical scheduling methods which included Evolutionary Fuzzy-Based Scheduling, Least Laxity First and Earliest Deadline First. The proposed GA had always recorded zero missed deadlines, lower average response time and showed high reliability during heavy system loads. Its non-preemptive and independent task design was effective in enhancing the efficiency in the whole system. One of the merits of this study is its high level of empirical rigor and comparative benchmarking. But it also assumes the same processors which restricts its ability to be adaptable to heterogeneous environments. Nevertheless, the research also provides strong empirical data that GAs may help a lot to improve the scheduling and optimization of the performance of real-time systems.

Chen & Hu (2022) explores the use of an adaptive enhanced genetic algorithm in intelligent control systems in agricultural greenhouses. The study aims at optimization of the multi-energy supply system to ensure that there are no fluctuations with changes in environment that results in temperature variation below 0.5 C and humidity variation below 1 percent RH. The dynamism aspect of the algorithm allowed it to adapt to changes in the environment dynamically, which proved its efficiency by being tested in real-life and not on a computer. This adaptive GA design

and practical validation combination highlights the ability of the algorithm to work with non-linear and multi-variable systems. This study has the limitation of being domain specific to agricultural systems but it has, on the other hand, proven the usefulness of GA optimization outside of computational settings into physical resource-driven intelligent control systems.

Sun & Sun (2025) published by IEEE identify a hybrid optimization model which combines genetic algorithms with artificial intelligence methods, i.e. convolutional neural networks (CNNs), to optimize product design processes. The hybrid solution offered 30 percent improved convergence rate, 25 percent greater design efficiency, cost reduction of 20 percent and 15 percent time to market. In case studies that were conducted in the automotive and consumer electronics industries, there was a notable increase in efficiency, durability and environmental sustainability. This combination of GA and AI was more successful in creating an exploration-exploitation balance that allows more adaptive optimization. But this is expensive in terms of computation, and is not very scalable in resource-constrained environments. Nevertheless, it is the future perspective of optimization studies in that it involves a combination of the evolutionary computation with the intelligent learning methods to effectively deal with high-dimensional multi-objective problems.

Zemliak (2022) suggested a variant of the Genetic Algorithm, which targets enhancement of optimisation in electronic circuit design. The most important innovation is the introduction of a control vector which reconfigured the calculation of the fitness function each time that the process reiterated. This is because the GA can more easily circumvent local minima and move to the global optimum by influencing the fitness landscape. Computational experiments indicated that this modified GA is able to minimise the CPU time by several orders of magnitude without reducing or worsening the accuracy of optimisation when compared to traditional GA methods. The control vector and its effect on the search trajectory are mathematically formulated in the study clearly, and thus, the method is theoretically powerful. Nevertheless, it has only been proven to be useful in simulated circuit-optimisation problems, and has not been directly tested on more general intelligent-system or AI data, casting doubts on its ability to extend to other domains.

Kahouli et al. (2021) explored the application of Genetic Algorithms and Particle Swarm Optimization to solve the problem of reconfiguration of the distribution network, which is intended to enhance reliability and minimize power losses. The authors have used the operational constraints of the IEEE 33-bus distribution network as a reference point to model objectives like energy not supplied (ENS) and active power losses. Comparison was made between GA, PSO and exhaustive search. The findings showed that PSO usually gave the fastest solution times, although GA was also competitive and had strong potential in working with multi-criteria optimisation problems. The research identifies the capability of GA to optimize network topology to enhance node voltages and line currents, which proves the usefulness of the method in the context of complex engineering issues. One of the weaknesses is that all the experiments are done in a simulated environment and no real world power grid is deployed, thus implementation challenges and scalability issues remain once more to be investigated.

Shi (2020) paid attention to the issue of deriving useful patterns out of extremely large amounts of data, when the classical database and data-mining tools become ineffective. The research hypothesized a better GA-based methodology that makes the process of identifying association rules and patterns that are applicable in big data better. The algorithm will seek to prevent early convergence and more fully search high-dimensional search spaces by optimizing genetic operators and incorporating AI-inspired modifications of mutation and selection. The experimental results showed that, the improved GA produced more accurate and efficient pattern discovery as compared to the classical GA implementations especially when noisy and redundant features are present. The paper highlights the significance of operator design and parameter tuning of large scale data environment. Nevertheless, the analysis was confined to offline experimental data and it was not embedded in the real time data-mining or streaming systems, which would be of relevance to most practical intelligent applications.

Halim et al. (2021) designed a better GA-based characterization method of features named GbFS to network intrusion-detection systems. The challenge brought about by high-dimensional network traffic data addressed by the authors can reduce the performance of classifiers and, therefore, raise the computation time. Their approach is a Genetic Algorithm mixed with a specially-purpose fitness function including machine-learning performance measures like

classification accuracy. The GbFS was tested on several benchmark datasets of intrusion-detection, such as UNSW-NB15, Bot-IoT, and CIRA-CIC-DOHBrw-2020. Findings indicated that the procedure resulted in significant feature reduction with the highest classification accuracies of 99.80, which is better than a number of established feature-selection methods. This proves that GA has a lot of potential in AI-based cybersecurity systems. However, the experiments involved curated datasets and not actual enterprise network traffic, and as such, it did not completely investigate issues like robustness of deployment, concept drift and real-time bottlenecks.

Synthesis of Findings

These six papers demonstrate the flexibility and strength of genetic algorithms in improving the functionality of intelligent systems in various areas of intelligent systems including robotics, real time computing, agriculture and design engineering. All the researches also seem to concur that optimization with the help of GA improves efficiency, flexibility, and system intelligence since the complex problems that are out of reach of conventional methods can be solved. Conceptual frameworks are set using theoretical literature by Naaman et al. (2025) and Tomforde (2023), whereas applied research by Chabane and Guenounou (2025), Hassan et al. (2025), Chen & Hu (2022), and Sun & Sun (2025) empirically validates this concept and innovates the hybrid model. The combination of GAs and AI that Sun and Sun showed can be seen as a paradigm shift towards more intelligent, self-optimizing systems. Despite the present difficulties in computational cost, domain applicability and real-world scalability, all these studies stand in agreement that genetic algorithm optimization is a paradigm shifting technology that would help in improving the efficiency, intelligence and strength of the current computational systems.

Chapter 3 : Research methodology

Methodology

4.1 Research Design

The research design employed in the study is software only, experimental research design in Python. There will be no hardware, robots and physical devices. The main goal is to compare:

- Baseline Genetic Algorithm (GA-1) A basic GA which performs feature selection.
- Enhanced Genetic Algorithm with Adaptive Mutation (GA-2)- a slightly advanced one that is also simple to implement.

Both of them will be assessed within an AI environment, with a single labelled dataset and a basic classifier.

4.2 Dataset

- Dataset UNSW-NB15 Intrusion Detection Dataset.
- Trustworthiness: Cybersecurity / AI-based intrusion detection.
- Reason for selection:
 - Popular metric in intrusion-detection studies.
 - Applied in Halim et al. (2021), so the results may be compared with the literature.
 - Numerical and categorical features are present in it and are appropriate in feature-selection experiments.

Preprocessing of the dataset will include the treatment of missing data, coding of categorical values, the normalisation of numerical data and the division into training and test sets.

4.3 Algorithms

1. Classifier (AI model):

- Logistic Regression (scikit-learn)

2. GA-1: Upper genetic algorithm in terms of features selection.

- Chromosome: Binary string, a bit indicates a feature to be selected (1) or not (0).
- Population Initialization: Binary random vectors.
- Fitness: The accuracy of the Logistic Regression when applied on validation set.
- Selection: Tournament selection.
- Crossover: Single-point crossover.
- Mutation: Bit-flip mutation, with constant, small probability (e.g. 0.05).

3. GA-2: Improved Genetic Algorithm of Adaptive mutation.

Same as GA-1, except with adaptive rate of mutation:

- In case of low population diversity (similar chromosomes in large numbers) enhancement in mutation probability.
- In case of high diversity, reduce mutation.

4.4 Procedure

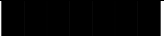
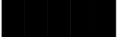
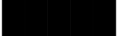
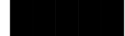
1. Clean, encode, normalise UNSW-NB15 (train/test split).
2. Run GA-1 for a fixed number of generations (e.g., 50–100) and record:
 - Best accuracy, number of selected features, and runtime.
3. Test GA-2 using the same settings and measure the same metrics.
4. Compare performance in GA-1 and GA-2 in regard to:
 - Accuracy of classification (test set).
 - Number of features selected.
 - Generation rate of convergence (fitness).
 - Computation time.

Matplotlib can be used to create simple plots (accuracy vs. generations)

5. Expected Outcomes

- A reproducible AI-based feature selection framework with one benchmark dataset.
- The proof of the ability of the enhanced GA with adaptive mutation (GA-2) to outperform the baseline GA in terms of accuracy, convergence, or feature reduction with ease of implementation.
- Reduction of the number of features in the models representing the Logistic Regression resulting in easier-to-understand models with similar or improved performance.
- A well-defined methodology that can be re-used or applied to other AI problems without complicated hybrid algorithms and specialized hardware.

Gantt Chart

Task	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Literature review & background						
Dataset acquisition & preprocessing						
Implementation of GA-1						
Implementation of GA-2 (adaptive)						
Experiments & performance analysis						
Writing, revision, and final report						

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