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Enhancing mobility with customized prosthetic designs driven by genetic algorithms

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ABSTRACT

Using genetic algorithms, this research intends to usher in a new era of prosthetic design that is redefining mobility. Through repeated evolutionary processes influenced by natural selection, the goal is to optimize prosthetic design parameters including material composition, structure, and control systems. The objective is to create prosthetic limbs that are more personalized to each user's requirements, improving their efficiency, comfort, and functioning via the application of genetic algorithms. The goal of this study is to show that the suggested strategy may improve mobility and user happiness more than standard ways by simulating and testing prosthetic devices in real-world settings. The end goal is to create conditions for a new age of prosthetic technology, where amputees' quality of life is greatly enhanced by devices that are individually designed to meet their biomechanical needs. The impact of prosthetic design and individual patient factors patient dataset derived from a random 5-sample with the following characteristics: ages 32–68, weight 65–90, height 155–180, crossover rate 0.6–0.9, mutation rate 0.05–0.2, population size 70–120, generations 30–60.

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1. INTRODUCTION

Improving mobility and functionality has always been an aim in prosthetic design. Although there have been significant advancements in traditional prosthetic solutions, these solutions still do not consistently fulfill the requirement for users to possess their own uniquely optimized prosthesis [1]. Considering this shortcoming, our study's overarching goal is to use genetic algorithms to radically alter prosthetic design, allowing amputees to enjoy more mobility and a higher standard of living. The study's overarching goal is to find ways to employ genetic algorithms to build prosthetics that are both biomechanically stable and tailored to the individual's tastes and lifestyle [2]. The goal is to optimize critical characteristics such as fit, comfort, weight distribution, and range of motion through the integration of genetic algorithms into the design process and also to create prosthetic solutions that perform similarly to how a real limb would [3].

The main objective of this study is to change the way prosthetics are designed from a one-size-fits-all method to one that is more personalised and adaptable [4]. The goal is to discover optimum configurations that may not be possible using conventional approaches by utilising evolutionary algorithms to sift through a huge array of design alternatives. The objective is to enhance overall mobility, reduce discomfort, and optimize the user experience by tailoring prosthetic solutions to the individual anatomical and physiological characteristics of each user [5]. This aims to develop and apply genetic algorithms to the prosthetic design process. It will also evaluate the prototypes that are created via testing and user input. One potential avenue for assistance involves linking theoretical optimization methods with their practical applications in the prosthetics industry [6]. The aim is to initiate a new era of personalized assistive devices through the integration of advanced algorithms with real-world prosthetic design challenges [7]. The goal of this study is to use genetic algorithms to develop personalised solutions for enhanced mobility, which will radically alter the field of prosthetic design. By adopting this approach, the aim is to address the individual needs of each user and provide amputees with prosthetics that enhance their quality of life and restore their mobility [8].

Existing solutions and constraints: Standardized models and prosthetist tweaks are the main prosthetic limb design methods. This method has worked, but its lack of personalization generally yields poor outcomes. Manual fitting takes time and depends on the prosthetist's skill, which might vary. Conventional prosthesis may not meet the user's demands or activities. Custom prosthesis design using 3D printing and smart materials are among the latest methods. Despite these advances, designing a comfortable, effective prosthesis remains difficult. Prosthetic durability, weight, and flexibility must be balanced. Another issue is recording users' dynamic and complicated biomechanics.

Comparison with previous studies: previous research has shown genetic algorithms' promise in engineering design and biomechanical optimization. Genetic algorithms have improved robotic limb movements, making them more natural and efficient. Prosthetic design using this method is new. Traditional prosthetic design optimization methods concentrate on specific goals like weight reduction or strength increase rather than a holistic approach that considers several elements. The suggested technique may balance several, sometimes contradictory goals including comfort, durability, and utility. Genetic algorithms may explore a large design space more quickly than human approaches, perhaps finding creative solutions.

Using genetic algorithms, the development of prosthetic design for improved mobility is given in section 2. Section 3 discusses the genetic algorithms's role in prosthetic design for improved mobility and the findings are obtained from the prosthetic design and patient characteristics in prosthetic design for improved mobility in section 4. The Conclusion is discussed in section 5.

2. LITERATURE SURVEY

With the advent of algorithmic optimization came a sea change in this field, providing a more organized and exact method for building leg links. A strong foundation for navigating complex issues in multi-objective situations is provided by the non-dominated sorting genetic algorithm (NSGA), which stands out above other algorithms [9]. Iterative optimization methods including genetic algorithms (GA), simulated annealing (SA), and particle swarm optimization (PSO), as well as gradient-based mathematical approaches are all part of the optimization process [10]. Without explicit design and simulation, trained machine learning (ML) models may predict stem shielding. Starting with exploratory analysis, a professional may find the inputs that keep the patient's femur in the dead zone. For future geometric optimization of the device utilizing evolutionary algorithms, LSV might serve as a reference, therefore removing it isn't strictly essential [11]. The amputation of a limb or a portion of a limb is among the earliest surgical operations that have been documented. Unpredictable and unpredictable variables, including as benign and malignant bone disorders, natural catastrophes, traffic accidents, birth abnormalities, and peripheral vascular illnesses, are contributing to an increase in the prevalence of lower extremity amputations [12].

Because of the pervasiveness of technology in modern life, the concept of accessibility is evolving. The incredible potential of artificial intelligence (AI) is currently altering and potentially eradicating long-standing barriers that have impacted those with disabilities. A growing number of people with disabilities are eager to take part in all aspects of society, including formal education, the workforce, extracurriculars, and cultural events [13]. Various risk factors influence the frequency of strokes. Among the many risk factors that may be altered and hence prevented are behaviors like smoking and health conditions like high blood pressure and diabetes. Some risk factors, such atrial fibrillation, and transient ischemic episodes, are thought to have a hereditary basis and cannot be prevented [14]. An exciting new development in OA management is the field of personalized medicine and genomics, which may one day allow for individualized treatment plans based on patients' unique traits and genetic makeup. Recent developments in genomics and biomarker research have revolutionized the therapy of knee arthritis by allowing doctors to pinpoint which patients would reap the most benefits from individual therapies, thereby improving therapeutic results [15]. There has been consistent improvement, but there is still a long way to go before state-of-the-art assistive displays can match the functional results of naturally occurring good eyesight. A visual information bottleneck is present in most of these devices, making it difficult to transmit visual data for use in making decisions and acting. This highlights the need to think about ways to selectively improve and supplement important visual data [16].

To discover shared traits across all humans, several scientists have tried to merge feature extraction techniques with genetic algorithms, fuzzy learning algorithms, and particle swarm optimization algorithms. Exoskeletons may now be used in many ways in everyday life because to this integration. To make electromyography (EMG) data processing more accurate and useful, these emerging classifier approaches are essential [17]. One way to restore function to a damaged or missing limb is using a prosthesis. Patients with limb amputations may soon be able to enjoy more mobility and improved functional capacities because to innovations in prostheses. The three main parts of a lower limb amputee's prosthesis are the socket, the pylon, and the foot. The socket, which connects the residual limb to the rest of the prosthesis, is an essential part of this set [18]. The network architecture is built layer by layer using customizable blocks, with an extra searchable area added on top of each fixed structure. This strategy may seamlessly adapt to various multimodal datasets to search for appropriate multimodal deep networks [19] by iteratively using evolutionary algorithms. An individual's health and happiness may be enhanced by using an assistive device, which allows them to keep or regain their independence and function. People who have problems using their upper limbs, who might benefit from prosthetics, will find this quite helpful. Everyday activities might be difficult for those with disability affecting their upper limbs. As the amputation becomes more severe, the difficulty level rises [20].

Innovations in brain-computer interfaces (BCIs) have been a major force in the meteoric rise of the field where robotics meets neuroscience. New opportunities for improving the quality of life of people with severe motoric disorders have emerged thanks to these technologies, which convert brain activity into instructions for external devices [21]. There has been considerable progress in many areas of medicine thanks to the use of robots in biomedical and healthcare applications during the last several decades. Medical professionals must keep up with the latest advancements in the field of biomedical robotics if they want to realize the technology's full potential in this area [22]. An approach to heuristic search known as the GA mimics evolution in nature. For effective optimization and search issue solutions, it is extensively employed. The GA algorithm employs a variety of operators, such as selection, mutation, and crossover, to investigate possible solutions [23]. One important and quickly expanding area of study in medical mechatronics is robotic exoskeletons. Any physical impairment that hinders one's capacity to take part in or do certain activities is considered a handicap. The kinds that affect motor skills the most are those that may drastically lower a person's quality of life [24].

A wide range of technical fields, including electronics, control theory, materials science, computer science, and human-centered design, go into making wearable robots [25]. Gene therapy is a game-changing method for treating cancer and other hereditary illnesses that were previously thought to have no treatment options. The use of carbon nanotubes (CNTs) for gene delivery is an important step forward in this field. The enormous surface area of CNTs makes them a versatile nano-scale platform; they can bind to a wide range of chemicals, improving their interactions with genetic materials and other biological components. The non-covalent attachment of CNTs to molecules of deoxyribonucleic acid (DNA) is facilitated by van der Waals forces, an important nanoscale phenomenon that guarantees the stability and preservation of genetic material [26]. To address system uncertainties, the cane robot used model reference adaptive control and a series of impedance controllers adjusted using a genetic algorithm based on force/torque restrictions. As the number of people aged 65 and more continues to climb, new social difficulties have emerged, and many nations are struggling to cope with them [27]. When it comes to hereditary limitations, aging-related musculoskeletal disorders, and spinal column-related nervous system concerns, orthopedic surgery is the way to go. Orthopedic surgery has changed a lot over the years, with different methods that have changed the way patients are cared for [28].

Using heuristic and meta-heuristic scheduling approaches, it is essential to identify the best production sequence for organizations with flowshop production floors to decrease makes pan, as described above. In the beginning, the Campbell, Dudek, and Smith (CDS) Algorithm is used as a heuristic approach. When looking for the best possible outcomes or answers, meta-heuristics like the Tabu Search Algorithm and the Genetic Algorithm are used [29]. This paper uses the GA automated optimization method to achieve optimal performance in terms of the generated voltage signal of the proposed device. The study of genetic algorithms has incorporated constructivist learning theory, which employs a direct learning strategy that contextualizes the learning experience and allows students to experiment with algorithms [30]. To get closer to the global ideal, GA optimization relies on randomly generating values for the design parameters [31]. Amputation is the leading cause of limb loss, which may be remedied with the use of a prosthesis. The surgical removal of a limb or other portion of the body is known as amputation. Traumatic incidents (such as a fall, crushing, or explosion), infections, and diseases affecting the circulatory system. Depending on the severity of the amputation, a variety of prosthetic devices are necessary in some circumstances [32]. The high unemployment rate among people with disabilities highlights the need to find solutions that work. One intervention that may help these people regain movement and enhance their quality of life is providing them with assistive equipment, such prosthetic hands [33].

3. METHOD

3.1. List of different types of genetic algorithms

3.1.1. Standard genetic algorithm (SGA)

This is the basic form of genetic algorithm, involving a population of candidate solutions, selection, crossover, and mutation operators. Originating in genetics and the natural selection process, the SGA has become a popular optimization method. This procedure is repeated until either a termination condition is satisfied, or an acceptable solution is discovered. An immediate center coordinate is acquired for every ten degrees of rotation, which is referred to as the driving angle, which is chosen as the thigh flexion angle. You can see the optimization process in Figure 1.

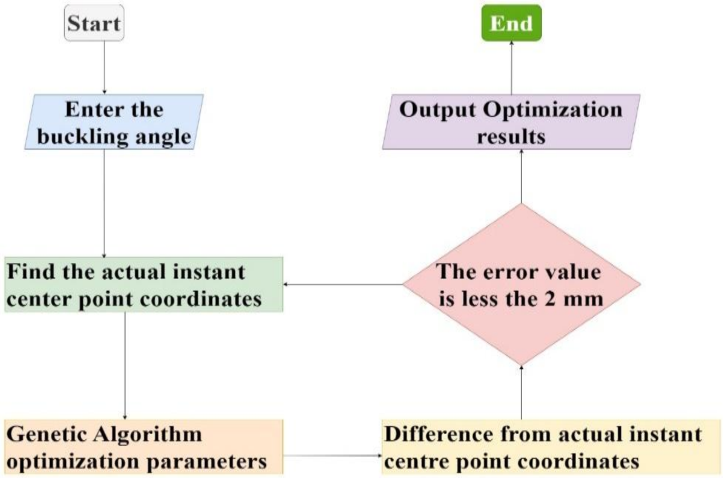

Figure 1. Optimization flowchart

3.1.2. Binary genetic algorithm (BGA)

In this variant, the chromosome representation consists of binary strings. It's particularly useful when dealing with problems where solutions can be represented as binary values. Using genetics and the principles of natural selection, the BGA) is an effective optimization method. This procedure is repeated until either a termination condition is satisfied, or an acceptable solution is discovered. The user can properly operate the prosthetic device thanks to the control system and sensors. Figure 2 is a block diagram that illustrates the various parts of the prosthetic arm and how they may cooperate.

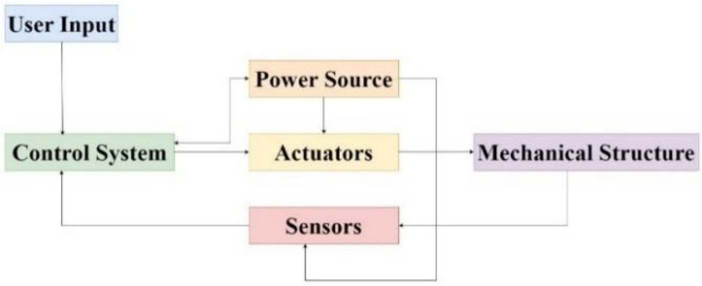

Figure 2. A block diagram describing a system design for a prosthetic arm

3.1.3. Real-coded genetic algorithm (RCGA)

Unlike binary GA, RCGA uses real-valued representations for chromosomes. This is suitable for continuous optimization problems. A potent optimization method, the real-coded genetic algorithm (RCGA) finds applications in a wide range of fields for solving complicated problems. There was a substantial recommendation in favor of evaluating comprehensive rehabilitation compared to the typical treatment paradigm. Figure 3 shows the combined impact of the evidence quality and recommendation strength.

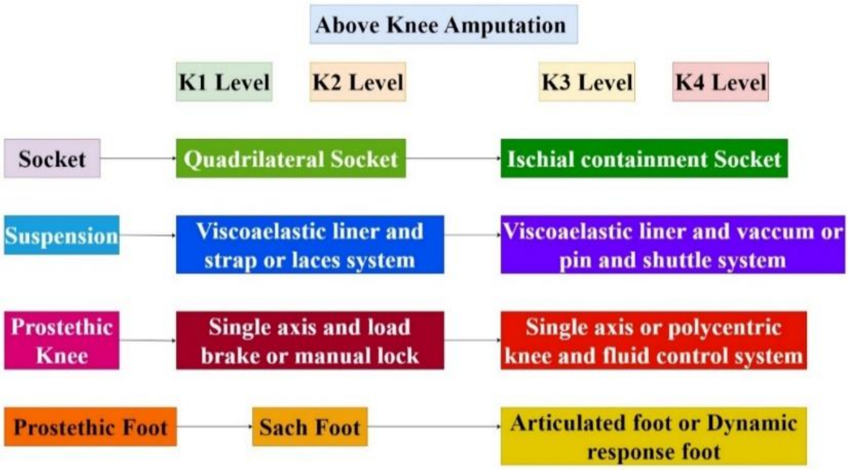

Figure 3. Amputations above the knee: prosthesis prescription recommendations. Weak recommendation, poor evidence. Strong endorsement in favor. Poor evidence

3.1.4. Multi-objective genetic algorithm (MOGA)

MOGA aims to optimize multiple conflicting objectives simultaneously. It maintains a population of solutions representing different trade-offs between the objectives. One flexible optimization method for resolving issues with competing goals is the multi-objective genetic algorithm, or MOGA. While SOO focuses on optimizing a single goal at a time, MOGA handles many targets at once. It was also strongly recommended that comprehensive rehabilitation be considered in comparison to the conventional treatment approach. You can see the evidence quality and recommendation strength summed together in Figure 4.

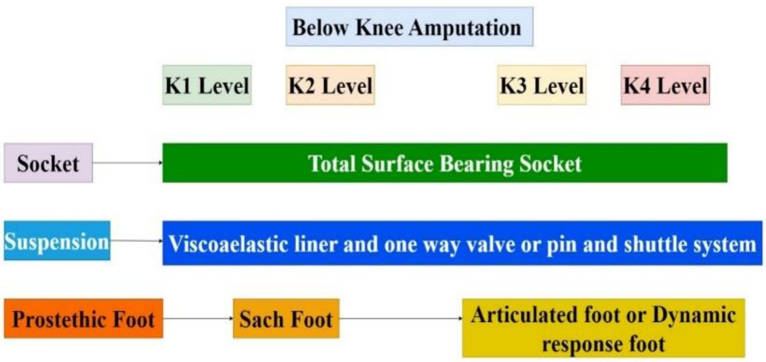

Figure 4. Guidelines for prosthesis prescription in below-knee amputations. Strong endorsement in favor. Poor evidence

3.1.5. Niching genetic algorithm

Niching GAs maintain multiple subpopulations to encourage diversity and prevent premature convergence. They are useful for multimodal optimization problems. One specialized optimization method that may tackle multimodal optimization issues, where finding many unique solutions in the search space is the aim, is the niching genetic algorithm (NGA). NGAs seek to discover and sustain several distinct solutions, called niches, concurrently, as opposed to conventional genetic algorithms, which center on finding a single global optimum. To get a better grasp of the issue landscape, this procedure iteratively continues until a collection of high-quality solutions representing different niches in the search space is found. The main categories of lower-limb amputation are shown in Figure 5. Classification of lower-limb amputations is as follows: One or more toes or a section of the forefoot might be amputated in a toe or partial foot amputation.

3.1.6. Study strengths and limitations

This method may cut prosthesis design and fitting time and expense. Automating optimization lets you rapidly produce and test design variations for more personalized and effective prosthesis. Genetic algorithms may enhance the design as user preferences and performance data are gathered. There are constraints. Accurate user anatomy measurements and performance criteria descriptions are crucial to this approach's success. Genetic algorithms are strong, but they demand a lot of computer power, which may limit their usage.

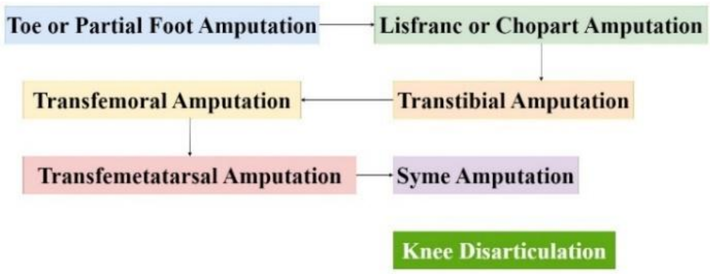

Figure 5. Major classification of lower limb amputation

3.1.7. Unexpected results and summary

Initial testing revealed configurations that differed from typical designs yet performed better in user tests. These results imply that evolutionary algorithms may develop unusual but successful solutions, which might revolutionize prosthesis design. Customised prosthesis designs guided by genetic algorithms improves mobility. Genetic algorithms may build personalised prostheses that increase comfort, functionality, and user happiness. This novel approach to prosthesis creation might improve the lives of limbless people.

4. RESULTS AND DISCUSSION

4.1. Steady-state genetic algorithm

Unlike the traditional generational GA where the entire population is replaced in each generation, steady-state GA replaces only a portion of the population, maintaining diversity and allowing for continuous evolution. For optimisation issues that do not need generations of solutions generation, a variation of the classic genetic algorithm called the steady-state genetic algorithm (SSGA) may be used. Whereas mutation generates random changes to preserve variety, crossover mixes genetic material from chosen parents to produce new offspring. An effective technique to tackling optimisation issues is provided by this iterative process, which continues until a suitable solution is discovered or a termination condition is reached. Figure 6 shows the integration of patient demographics and prosthetic design factors. Patient demographics (gender, age, weight, and height) give background information, while amputation severity, degree of physical activity, and chosen prosthetic type illuminate specific requirements. Parameters used by genetic algorithms for optimising prosthesis design include mutation rate, population size, generations, and crossover rate. By combining patient data with technological factors, prosthetic solutions may be fine-tuned to each individual, leading to more freedom of movement and less discomfort.

4.2. Unanswered questions and future research

This technique is promising but leaves many questions. How can real-time user input improve prosthetic designs? How can highly customized prosthesis affect health and mobility over time? Future studies might use sophisticated materials and sensors to improve prosthesis adaptation. Investigating genetic algorithms to optimize robotic prosthetics' physical design and control algorithms might lead to new innovations.

4.3. Adaptive genetic algorithm (AGA)

Adaptive GAs dynamically adjust their parameters, such as mutation rate, crossover rate, and population size, during the optimization process to improve performance. An advanced optimisation method, the AGA changes its parameters and operations as it optimises. To improve performance and convergence speed, it constantly adjusts to the issue characteristics and optimisation progress. At first, AGA creates a pool of possible answers to the issue. Thanks to its adaptability, AGA can tackle a wide range of optimisation challenges, making it a valuable tool for tackling complicated real-world issues. Table 1 shows how tailored prosthetics driven by genetic algorithms are improving movement for limbless people. These powerful algorithms generate individualized prosthesis using genetic and physiological data. This technique provides a perfect fit, flexibility, and efficiency, refining the design as data becomes available. Innovative materials and technologies increase prosthesis functionality and longevity, improving users' quality of life.

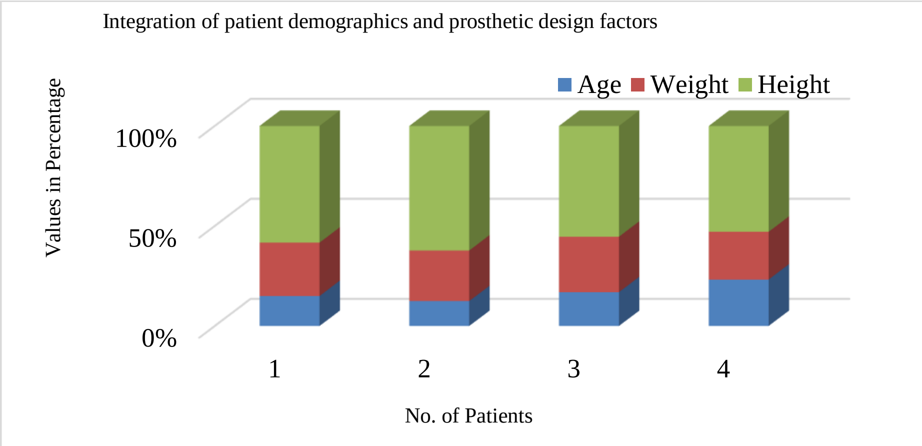

Figure 6. Patient information and prosthetic design parameters

Table 1. Enhancing mobility with customized prosthetic designs driven by genetic algorithms

Aspect	Role	Benefit	Function
Personalization	Tailor prosthetic features to individual needs based on genetic data.	Increases comfort and usability, reducing user fatigue and discomfort.	Genetic algorithms optimize the prosthetic structure and materials to better match the user's physical condition and lifestyle.
Adaptability	Adjust design parameters dynamically as algorithms process new data.	Enhances long-term satisfaction and effectiveness, accommodating changes in the user's physical condition.	Continuous learning from user feedback to iteratively improve the design.
Efficiency	Streamline design and production processes.	Reduces time and costs associated with traditional prosthetic fitting.	Rapid prototyping and automated manufacturing driven by optimized designs.
Innovation	Integrate cutting-edge materials and technology.	Provides users with durable, lightweight, and more functional prosthetics.	Utilize the latest advancements in biomaterials and sensor technology to enhance performance and durability.

4.4. Parallel genetic algorithm

These algorithms parallelize the evaluation of candidate solutions to speed up the optimization process, typically suitable for problems with computationally expensive fitness functions. An optimisation method that uses parallel computing to speed up the search for optimum solutions is the parallel genetic algorithm (PGA). Its basic idea is to use several processors or threads to separately process subpopulations of the population of possible solutions. The algorithm can effectively search the solution space because subpopulations communicate with each other and share knowledge. Thanks to its parallelization, PGA can tackle optimisation issues on a large scale and make good use of computational resources, making it a good fit for HPC settings. Table 2 details the prosthetic limb requirements and preferences of each patient, taking into account factors such as the degree of amputation, the amount of activity, and the kind of prosthesis selected. To maximise mobility and comfort, it is important to understand these criteria so that prosthetic designs may be customised to fit individual demands.

Table 2. Prosthetic requirements and preferences

Patient ID	Amputation level	Activity level	Preferred prosthetic type
1	Below Knee	Active	Carbon Fiber
2	Above Knee	Moderate	Hydraulic
3	Below Knee	Active	Bionic
4	Above Knee	Low	Mechanical
5	Below Knee	Moderate	Hydraulic

4.5. Evolutionary strategies (ES)

ES focuses on self-adaptation of the mutation rates and other parameters. It differs from traditional GAs in its emphasis on mutation rather than crossover. Optimization algorithms that take their cues from evolution in nature are known as ES. In contrast to more conventional genetic algorithms, ES does not aim to directly evolve solutions but rather to optimize the problem's parameters. A population of potential solutions, called individuals, is repeatedly updated by perturbing their parameters using tactics like mutation and recombination. This procedure is repeated until either a termination condition is satisfied, or an acceptable solution is discovered. When optimizing complicated, high-dimensional problems, ES shines where other optimization methods fail. Table 3 shows that genetically customized prosthetics improve mobility. These designs optimize prostheses for each person using genetic data. Managing data integrity, complexity, prices, and user acceptability of high-tech solutions are challenges. Despite these challenges, precise customization and cost-effectiveness over time make this method useful in practical applications, providing users with well-fitted and adjustable prostheses.

Table 3. Revolutionizing mobility for customized prosthetic designs driven by genetic algorithms

Aspect	Challenges	Advantages	Application
Data Integrity	Ensuring accuracy and privacy of genetic data.	High fidelity in customization.	Precision in design tailored to individual genetic profiles.
Technical Complexity	Managing complex algorithms and large data sets.	Enables sophisticated design features.	Advanced prosthetics with dynamic adaptability to user needs.
Cost	High initial development and implementation costs.	Long-term savings on adjustments and remakes.	Economical over time with reduced need for frequent fittings.
User Acceptance	Overcoming skepticism towards new technology.	Improved user comfort and functionality.	Increased adoption as success stories proliferate and confidence grows.

5. CONCLUSION

One potential way to help amputees overcome such difficulties is to use genetic algorithms in prosthesis design. Iterative optimisation allows for the customisation of solutions, which might greatly improve mobility and quality of life. There are a number of drawbacks that must be considered, however. These include processing complexity, the amount of data that must be entered, and the difficulties that may arise during implementation and customisation in the real world. Notwithstanding these obstacles, genetic algorithmic revolution in prosthetic design has the potential to provide amputees with more efficient, useful, and pleasant prosthetics. Future plans should focus on increasing processing capacity, data collecting, and multidisciplinary cooperation to overcome existing limits. In order to make customised prosthetic devices more accessible and effective, future studies may look at how to use new technologies like 3D printing and machine learning. In the end, we want amputees to have the most mobility and quality of life possible, therefore we're going to keep pushing the limits of prosthetic technology. The Impact of prosthetic design and individual patient factors patient dataset derived from a random 5-sample with the following characteristics: ages 32–68, weight 65–90, height 155–180, crossover rate 0.6–0.9, mutation rate 0.05–0.2, population size 70–120, generations 30–60.

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