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Application of particle swarm optimization algorithm in medical diagnostics

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ABSTRACT: The article discusses the application of the PSO algorithm in various fields, including medicine, engineering, economics, and finance, highlighting its computational efficiency. It also emphasizes the use of the algorithm to find optimal solutions in both continuous and discrete optimization problems.

As an application of the considered algorithm, a prediction problem was solved to determine the presence or absence of cardiovascular diseases in individuals based on a selected training sample.

As a result, informative features were extracted from the available features in the sample, which were used to calculate the diagnostic accuracy indicator, and the best coefficients for making predictions were found.

KEYWORDS: *particle swarm, optimization, MSE, PSO, fitness function, position, inertia, solution, RMSE.*

I. INTRODUCTION

Medical diagnostics is one of the key areas of modern medicine, on which the accuracy and timeliness of diagnosis depend, and therefore the effectiveness of treatment. With the development of information technology and artificial intelligence methods, automated systems that can improve the diagnostic process come to the fore [1-2]. One of the promising methods for solving optimization problems in the medical field is the particle swarm optimization algorithm (PSO). This article discusses the possibilities of using the PSO algorithm to solve problems of diagnosing cardiovascular diseases. The advantages of the algorithm are discussed and examples of its successful use in real medical applications are demonstrated.

Particle Swarm Optimization (PSO) is an optimization algorithm inspired by the social behavior of birds and fish. It works by launching a swarm of particles in a search space, where each particle represents a potential solution. Particles move through the search space by adjusting their positions according to the best positions found by the swarm and their own best positions, thus converging towards an optimal solution [3]. It is worth noting that PSO is a popular algorithm in the fields of artificial intelligence and machine learning.

II. MATERIALS AND METHODS

PSO is a powerful optimization method that can be used to solve a wide range of optimization problems. It is employed in various fields, including medicine, engineering, economics, and finance, and is computationally efficient. PSO can be used to find optimal solutions in both continuous and discrete optimization problems. The algorithm is based on the concept of social learning, where each particle in the swarm learns from its own experience and the experiences of other particles in the swarm. PSO is a global optimization algorithm that does not require any gradient information, making it very robust [4].

However, the classical version of the algorithm and many of its modifications have significant limitations, as the optimized function must be smooth and continuous, meaning it is not suitable for discrete functions.

The diagram shown in *Figure1* illustrates the algorithm passing optimized parameters to a fitness function and retrieving the fitness value (evaluation criterion). This chart is inconvenient for users, particularly traders, to create problem-solving applications, as testing cannot be performed based on past data.

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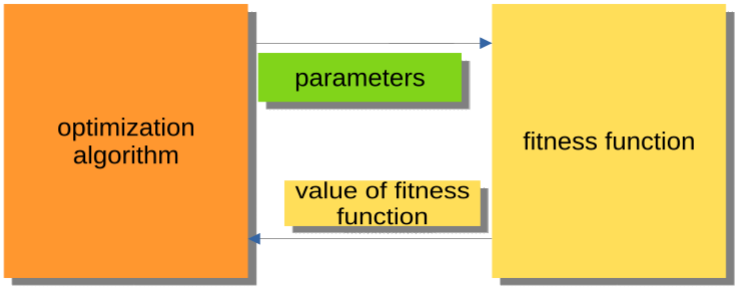

Figure 1. Diagram of the interaction between the PSO algorithm and the fitness function

The chart shown in *Figure2* is more convenient, where the optimization algorithm is not an independent program but a separate module or "black box". This module has min, max, and step parameters for each argument being optimized. The MQL (Meta Quotes Language) program receives the optimized arguments upon request and returns the fitness values, or in other words, the values of the fitness function. This scheme allows for the creation of a range of highly flexible solutions, from using Expert Advisors for automatic optimization to writing a customized optimization manager.

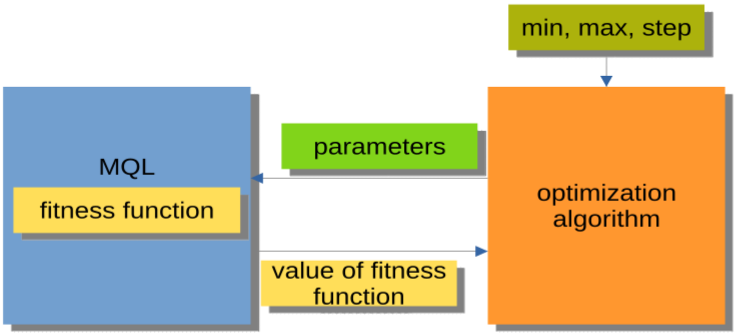

Figure 2. Diagram of the interaction between the MQL program and the PSO

Now, let's take a closer look at the particle swarm optimization (PSO) algorithm. A particle swarm system consists of many particles that interact with each other and with the environment. Although there is no centralized control system to dictate the behavior of each particle, they follow certain simple rules. The local and random interactions among them lead to the emergence of intelligent group behavior, not controlled by humans.

Each particle in the swarm performs the following simple tasks [5-6]:

- The particle avoids collisions with other particles.
- The particle adjusts its velocity according to the velocities of other particles around it.
- The particle tries to maintain a very small distance from other particles in its vicinity.

The working scheme of the PSO algorithm includes the following logical steps:

1. Create random particles (initial iteration).
2. Calculate the fitness value for each particle.
3. Calculate the fitness value for all particles.
4. Adjust the velocity of the particles.
5. Check for a stopping point or proceed to step 2.
6. Complete the algorithm.

The PSO algorithm starts by initializing the population. In the second step, the fitness values of each particle are calculated, after which the individual and global best values are updated, meaning the velocities and positions of the particles are updated [7-8]. When using PSO, the potential solution of the numerical optimization problem is represented

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by the position of the particle. Additionally, each particle has a current velocity, which reflects an absolute value related to the new direction (relative to a better position/solution). Steps 2-4 are repeated until the termination condition is met. In the first step, all particles are scattered to find the best solution. Each particle is evaluated. According to the neighborhood topology, the best solutions are found, and the personal and global best values for each member of the swarm are updated. Convergence to the solution is achieved by attracting all particles to the best solution particle.

From a mathematical perspective, the following two equations are used to update the coordinates of the particles:

v(t+1) = w * v(t) + c1 * rp * (p(t) – x(t)) + (c2 * rg * (g(t) – x(t))

x(t+1) = x(t) + v(t+1)

The process of updating the position is actually much simpler than the proposed equations suggest. The particle velocity is updated based on the first equation. The term v(t+1) represents the velocity at time t+1. The new velocity depends on three conditions:

- **First**: *w * v (t)*. The coefficient w is called the inertia weight, and it is simply a constant; v(t)v(t)v(t) is the current velocity at time t.
- **Second**: *c1 * rp * (p(t) – x(t))*. The multiplier *c1* is a constant called the cognitive weight, and the multiplier *rp* is a random variable in the range [0, 1]. The vector quantity *p(t)* represents the particle's best-known position at time *t*, while the vector quantity *x(t)* represents the particle's current position.
- **Third**: *c2 * rg * (g(t) – x(t)*. This term updates the velocity. The multiplier *c2* is a constant called the social (or global) weight. The multiplier *rg* is a random value in the range [0, 1]. The vector quantity *g(t)* represents the best-known position for any particle in the swarm at time *t*. *v(t+1)* is the updated velocity.

The PSO algorithm performs the search through particles that update from iteration to iteration. Each particle moves according to its previous best (*pbest*) position and the global best (*gbest*) position found by the swarm [4]. That is,

$$pbest(i,t) = \arg\min_{k=1,\dots,t}\left[f(P_i(k))\right],\ \ i \in \{1,2,\dots,N_p\},$$

$$gbest(t) = \arg\min_{\substack{i=1,\dots,N_p \\ k=1,\dots,t}}\left[f(P_i(k))\right] \tag{1}$$

Here, the index i represents a particle, N_p is the total number of particles, t is the current iteration number, f is the fitness function, and P is the position. The velocities V and positions P of the particles are updated using the following equations:

$$V_i(t+1) = \omega V_i(t) + c_1 r_1 (pbest(i,t) - P_i(t)) + c_2 r_2 (gbest(t) - P_i(t)) \tag{2}$$

$$P_i(t+1) = P_i(t) + V_i(t+1) \tag{3}$$

Here, V represents the velocity, ω is the inertia weight used to balance global search and local exploitation, *r1* and *r2* are uniformly distributed random variables in the range [0, 1], and *c1* and *c2* are positive constant parameters called "acceleration coefficients".

Usually, an upper limit is set for the velocity parameter. "Velocity clamping" is used as a method to restrict particles from flying out of the search space. The first part of equation (2), called "inertia", includes the previous velocity that provides the necessary momentum for particles to move across the search space, while the second part, called the "cognitive component", represents an individual particle. This encourages particles to move towards the best positions found so far. The third part of this formula, known as the "social component", represents the collective interaction of particles to find the global optimal solution [9-10].

Below are some problems that can be efficiently solved using the PSO algorithm:

1. **Function Optimization:**
    - PSO is widely used for optimizing mathematical functions with one or multiple variables. This algorithm is effective in finding the minimum or maximum value of complex functions with multiple variables.

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2. **Engineering Design Problems:**
   - Structural design optimization, such as optimizing the shape or material of a structure to maximize strength and minimize weight.
   - Electrical engineering problems, including circuit and control system design.
   - Mechanical design, such as optimizing the performance of engines or other mechanical parts.
3. **Machine Learning and Data Mining:**
   - Training neural networks by optimizing weights and biases.
   - Feature selection, where PSO is used to select the most suitable features for a model.
   - Clustering problems, such as optimizing centroids in k-means clustering.
4. **Robotics and Path Planning:**
   - Optimizing the path for a robot to move efficiently across an environment.
   - Coordinating multiple robots to achieve a common goal while avoiding collisions.
5. **Resource Allocation:**
   - Scheduling problems, including planning work tasks or projects that need to be allocated to resources optimally.
   - Load balancing in networks to distribute workloads efficiently, such as in cloud computing.
6. **Control Systems:**
   - Tuning PID controllers for various industrial processes.
   - Solving optimal control problems where the goal is to find the best control strategy to achieve a desired outcome.
7. **Economics and Finance:**
   - Portfolio optimization, where the PSO algorithm is used to find the best asset allocation to maximize returns and minimize risks.
   - Pricing and financial forecasting models.
8. **Telecommunications:**
   - Optimizing the placement of antennas and other network infrastructures.
   - Allocating channels in wireless networks to reduce interference and maximize bandwidth usage.
9. **Bioinformatics:**
   - Sequence alignment and protein structure prediction.
   - Gene expression analysis and genetic network inference.
10. **Environmental and Energy Systems:**
   - Optimizing the configuration of renewable energy systems such as wind farms or solar panel arrays.
   - Environmental monitoring, such as optimizing the placement of sensors to detect pollutants.
11. **Medicine:**
   - Medical image processing and segmentation: The PSO algorithm is used for segmenting medical images, making it easier to identify organs and detect pathologies in tissues.
   - Medical diagnosis: PSO can be used in diagnostic systems. By finding the best parameters from medical datasets, it helps improve diagnostic accuracy.
   - Treatment plan optimization: PSO is used to optimize treatment plans for individual patients. For example, it helps in optimizing radiotherapy plans to maximize benefits while minimizing harm to patients.
   - Drug design and optimization: PSO is applied in optimizing drug molecules. It helps identify the best chemical and physical properties of molecules.
   - Electrocardiogram (ECG) signal analysis: The PSO algorithm can be used for processing and analyzing ECG signals, aiding in the early detection of heart diseases [11-13].

PSO is particularly useful for solving problems with large, complex, and poorly understood search spaces where traditional optimization methods may be challenging. Its ability to combine good solutions with relatively simple implementation and a few parameters to tune makes it a versatile tool used across various fields.

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III. RESULTS AND DISCUSSION

As a clear example of the application of the PSO algorithm, we will consider the problem of predicting the presence or absence of cardiovascular disease in individuals based on a training dataset. The training dataset is obtained from the following link: Cardiovascular Disease Dataset. This cardiovascular disease dataset file was collected from a multi-specialty hospital in India. The dataset consists of 1000 objects with 12 features each. This dataset is useful for detecting heart diseases at early stages, as well as for creating predictive models for machine learning. Additionally, this file helps in predicting similar objects in the dataset based on the PSO algorithm. The features in the dataset and their descriptions are provided in the following table:

№	Attribute	Assigned Code	Unit	Type of the data
1.	Patient identification Number	patientid	Number	Numeric
2.	Age	age	25-80	Numeric
3.	Gender	gender	0,1 (0-Female, 1-Male)	Binary
4.	Chest pain type	chestpain	1,2,3,4 (0-typical angina; 1-atypical angina; 2-non angina pain; 3-asymptomatic)	Nominal
5.	Resting blood pressure	restingBP	94-200 (in mm HG)	Numeric
6.	Serum cholesterol	serumcholestrol	126-564 (in mg/dl)	Numeric
7.	Fasting blood sugar	fastingbloodsugar	0,1>120 mg/dl (0-false, 1-true)	Binary
8.	Resting electrocardiogram results	restingrelectro	0,1,2 (0-normal; 1-having ST-T wave abnormality (T wave inversion and/or ST elevation or depression of >0.05 mV), 2-showing probablerdefinite left ventricular hypetrophy by Estes' criteria)	Nominal
9.	Maximum heart rate archived	maxheartrate	71-202	Numeric
10.	Exercise induced angina	exerciseangia	0,1 (0-no, 1-yes)	Binary
11.	Oldpeak ST	oldpeak	0-6.2	Numeric
12.	Slope of the peak exercise ST segment	slope	1,2,3 (1-upsloping, 1-flat, 3-downsloping)	Nominal
13.	Number of major vessels	noofmajorvessels	0,1,2,3	Numeric
14.	Classification	target	0,1 (0-Absence of Heart Diese, 1-Presence of Heart Diese)	Binary

Here are the results obtained using the PSO algorithm:

```
Informative features index: [ 1  2  6  7  9 10]
Informative features:
gender
chestpain
restingrelectro
maxheartrate
oldpeak
slope
Best score: 0.9866666666666667
>>>
```

Coefficients obtained for the multivariate linear regression problem formulated based on the given data in the sample file using the PSO algorithm:

```
Best coefficients: [-0.15811528  0.04902925  0.04684222  0.00052059 -0.00608593  0.36515823]
Best RMSE: 0.29650797380566046
RMSE on the test set: 0.2817441498759174
>>>
```

1. *Best Coefficients:* The best coefficients of the linear regression model obtained using the PSO algorithm.
2. *Best RMSE:* The best RMSE found during the PSO algorithm process.
3. *RMSE on test set:* The RMSE between the actual and predicted values on the test set.

RMSE (Root Mean Squared Error) is a metric used to measure the accuracy of a model's predictions. It calculates the square root of the average of the squared differences between the predicted values and the actual values. RMSE is used to assess the error of the model; the smaller this value, the better the model is considered to be.

The mathematical expression for RMSE is as follows:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

Where:

- n is the number of observations,
- y_i is the actual value,
- $\hat{y}_i$ is the predicted value.

After finding the coefficients of the linear regression model optimized by the PSO algorithm, we calculate the RMSE metric. This program optimizes a multidimensional linear regression model using the PSO algorithm and evaluates the model's errors using RMSE.

*Figure*3 below shows the appearance of the coefficients corresponding to the given features for the multidimensional linear regression problem using the PSO algorithm.

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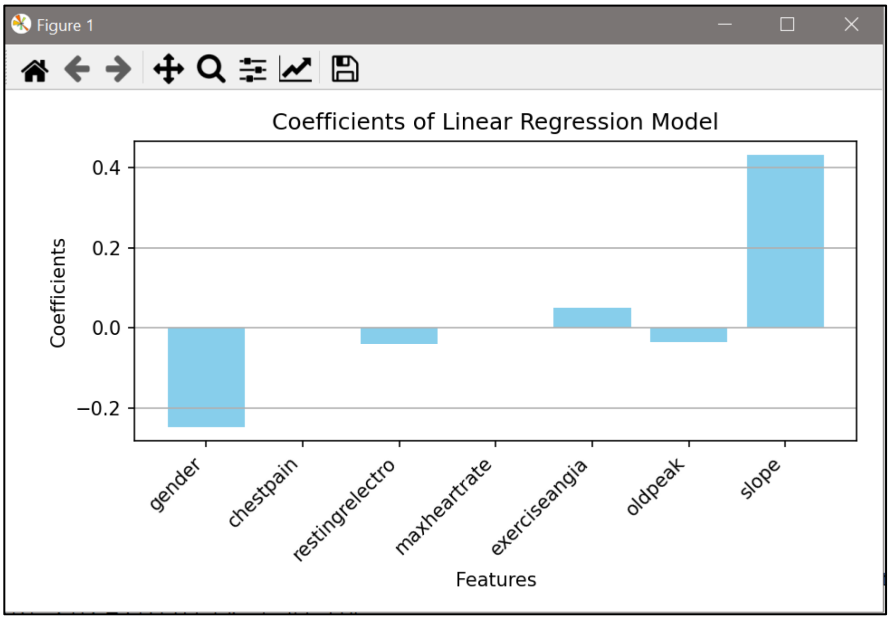

Figure 3. Features and Corresponding Best Coefficients

IV. CONCLUSION

Using the obtained results, predictions can be made on objects similar to those in the selection file that have not yet been passed to the algorithm. The prediction process is carried out using the best coefficients identified by the PSO algorithm. The results obtained for the problem solved above can be applied to various medical diagnosis issues.

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