

# Rank Based Binary Particle Swarm Optimisation for Feature Selection in Classification

Majdi Mafarja

Department of Computer Science, Birzeit University  
Birzeit  
mmafarja@birzeit.edu

Nasser R. Sabar

Department of Computer Science and Information  
Technology, La Trobe University  
Melbourne, Australia  
n.sabar@latrobe.edu.au

## ABSTRACT

Feature selection (FS) is an important and challenging task in machine learning. FS can be defined as the process of finding the best informative subset of features in order to avoid the curse of dimensionality and maximise the classification accuracy. In this work, we propose a FS algorithm based on binary particle swarm optimisation (PSO) and  $k$ -NN classifier. PSO is a well-known swarm intelligent algorithm that have shown to be very effective in dealing with various difficult problems. Nevertheless, the performance of PSO is highly effected by the inertia weight parameter which controls the balance between exploration and exploitation. To address this issue, we use an adaptive mechanism to adaptively change the value of the inertia weight parameter based on the search status. The proposed PSO has been tested on 12 well-known datasets from UCI repository. The results show that the proposed PSO outperformed the other methods in terms of the number of features and classification accuracy.

## CCS CONCEPTS

• **Computing methodologies** → **Feature selection**;

## KEYWORDS

Feature Selection, Classification, Particle Swarm Optimisation

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## 1 INTRODUCTION

Machine learning techniques have been widely used in various fields, e.g., image classification, pattern recognition, and disease classification [4]. Many fields involve huge datasets due to the advanced data collection tools and technologies. These fields suffer from the curse of dimensionality [14] and thus data reduction becomes a mandatory step to process them in a moderate amount of time. Feature Selection (FS) is a primary dimensionality reduction

form that aims to select the most informative subset of features from the original dataset (or set) to reduce the dimensionality of data.

Over the years several FS tools have been proposed. A traditional FS tool consists of two components: evaluation criterion and selection (search) algorithm. The evaluation criterion is used to assess the quality of the selected subset of features. It can be either filter, wrapper or embedded [29]. Filter approaches are simple and require light computational time since they depend on the relations between data itself when evaluating the selected subset, without employing an external evaluator [27]. Wrapper approaches are considered more efficient than filters but they may suffer from high computational cost. The main role of the selection (search) algorithm is select the most informative subset of features from the given set. Various search strategies have been used as a selection (search) algorithm [13]. They can be categorised into: complete, random, and heuristic search. In complete search, all possible feature subsets should be generated and evaluated to select the best feature subset. With the curse of dimensionality, this approach becomes impractical option. Random search selects feature subsets randomly. This approach may find a subset faster than the complete search, but at the worst case, it may perform worst than the complete search without finding the best subset. Heuristic search or meta-heuristics algorithms have been widely used in FS as they are very efficient, easy to implement and can handle large scale data.

A branch of meta-heuristics algorithms is the Swarm Intelligence (SI). SI algorithms mimic the natural behaviour of some creatures that live in flocks or groups like flocks of birds and ants [10]. Various SI algorithms have been utilised to tackle the FS problem in the literature such as GA [8], PSO [30], Ant Colony Optimization (ACO) [9], DE [31], Artificial Bee Colony (ABC) [32], Grasshopper Optimisation Algorithm (GOA) [20] and Particle Swarm Optimisation (PSO) [3], [28]. For more FS approaches, readers can refer to [1, 6, 15–19, 21, 24].

The PSO [5] is a primary SI algorithm that inspired from the self-organisation behaviour of birds. PSO is a population-based algorithm that maintains a swarm of particles. Each particle represents a complete solution to the problem at hand. PSO uses the so called velocity and position update equations to search for better solutions. In PSO, the optimisation process is accomplished in two phases: exploration and exploitation. In exploration, the whole feature space is searched to find new subsets in a different areas whereas in exploitation phase the already existing subsets are further improved. However, to get high quality solutions (subset of features) PSO need to adaptively alternate between these two

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phases. This is because having more exploitation than exploration, the PSO will get stuck at the local optima. At the same time, the PSO will lose some best solutions if it went far in exploration. In PSO, the exploitation and exploration phases are controlled by the inertia weight parameter. That is at the early stages of the optimisation process, PSO should explore many areas in the search space to find candidate solutions of the fittest attraction basins. Then at the later stages, the exploitation occurs around the discovered solutions in the previous space. However, the key challenging is how to have a proper inertia weight parameter that can cope with various problem characteristics. Several strategies were proposed to adaptively change this parameter. Harrison et al. [7] provided a comprehensive study about the used updating strategies for the inertia weight parameter.

In this work, we use an adaptive update strategy to adjust the value of the inertia weight parameter based on the search state. Instead of using static inertia values for all solutions, each solution will have a different inertia weight value based on its rank in the swarm. To assess the performance of the proposed PSO, twelve benchmark datasets were used and the result are compared with three similar approaches from the literature. The results showed the influence of having a proper control strategy on enhancing the performance of PSO algorithm.

The rest of this paper is organised as follows: Section 2 presents the methodology which consists the basic PSO algorithm and the proposed FS tool. In Section 4, the experimental results are presented and analysed. Finally, in Section 5, conclusions are given.

## 2 METHODOLOGY

In this section, we first present the basic PSO algorithm, followed by the binary PSO and the the proposed FS approach.

### 2.1 Particle Swarm Optimisation (PSO)

The PSO algorithm [5] is a population-based optimisation algorithm that operates on a swarm of particles. In PSO, each particle has two components known as the particle position and particle velocity. Particle's position represents a solution to given optimisation problem. Each solution is represented by vector of  $N$  real numbers, where  $N$  is the size (dimensionality) of the given problem. Particle's velocity represents the speed and direction that a particle should move in the search space. Both particle position and particle velocity are updated using Equation (1) and (2). In these equations,  $x$  represents the particle position and  $v$  is the particle velocity.  $pBest$  is the best personal position found by the  $i^{th}$  particle and  $gBest$  is the global best position found by the whole swarm.  $c_1$  and  $c_2$  are the acceleration parameters.  $r_1$  and  $r_2$  are two random variable in the interval  $[0, 1]$ .  $\omega_1$  is the inertia weight which controls the balance between exploration and exploitation phases. The main steps of PSO are as follows:

- (1) Initialise PSO parameters.
- (2) Evaluate the fitness value of the swarm.
- (3) Update the personal best ( $pbest$ ) and global best ( $gbest$ ).
- (4) Update the velocity and position of each particle using Equation (1) and Equation (2).
- (5) Check the stopping condition; if satisfied stop and return the best particle (solution); otherwise go to Step 2.

$$x_i^j(t+1) = x_i^j(t) + v_i^j(t+1) \quad (1)$$

$$v_i^j(t+1) = \omega_1 v_i^j(t) + c_1 r_1 (pBest_i^j - x_i^j(t)) + c_2 r_2 (gBest_j - x_i^j(t)) \quad (2)$$

### 2.2 Binary Particle Swarm Optimization

Binary PSO (BPSO) was proposed to deal with discrete optimisation problems. In BPSO, a solution (particle position) is represented by zeros and ones. Hence, the personal best ( $pBest$ ) and global best ( $gBest$ ) are restricted into "0" and "1". According to Kennedy and Eberhart [11], Mirjalili and Lewis [25], PSO can be converted into a binary version by using a transfer function that maps the velocity values to a real number between 0 and 1 as can be seen in Figure 1. In BPSO, the particle's velocity and particle's position are updated using Equation (3) and Equation (4).

$$S(v(t)) = \frac{1}{1 + e^{-v(t)}} \quad (3)$$

where  $rand$  is a random number  $\in [0, 1]$ .

$$x(t+1) = \begin{cases} 1 & \text{If } rand < S(v(t+1)) \\ 0 & \text{Otherwise} \end{cases} \quad (4)$$

where  $S(v(t))$  is the *Sigmoid function* as depicted in Figure 1

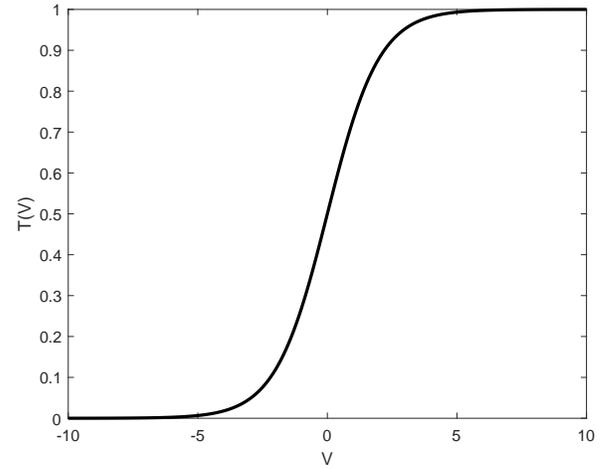


Figure 1: Sigmoid Transfer function

## 3 THE PROPOSED APPROACH

In this section, we discuss the main part of the proposed approach for FS. It consists of two parts: FS algorithm and the evaluation criterion. In the following subsections, the details of both parts will be presented.

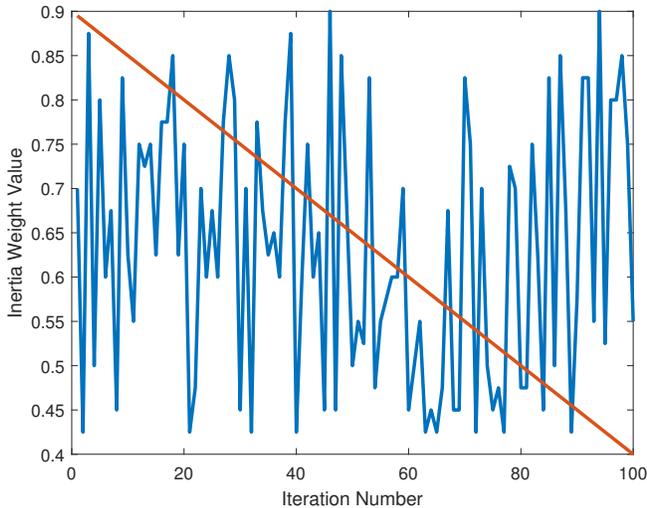
### 3.1 FS algorithm

In this work, we use BPSO to search for the best subset of features from the given dataset. BPSO is well suited to deal with discrete problems such as FS. Similar to a traditional PSO, BPSO needs to find the proper value of the inertia weight parameter ( $\omega$ ).  $\omega$  has

crucial impact on the performance of BPSO. In basic PSO and BPSO,  $\omega$  is fixed for all particles regardless of the search performance. This indicates that particle positions will be updated without considering their fitness value, i.e., the low-quality solutions will be treated as the high-quality ones. This can lead to low quality solutions as the search performance is often miss-led by bad quality ones. Thus, there is a need for a proper updating strategy for  $\omega$  that takes into account the fitness values of all particles. To address this issue, in this work, we use an adaptive updating strategy for  $\omega$ , originally proposed in Panigrahi et al. [26]. In this strategy, all particles (solutions) will be ranked based on their fitness values. The solutions with high fitness values will have small  $\omega$  values, while high values of  $\omega$  will be given to the low-quality solutions. A small value of  $\omega$  implies low-velocity value, i.e., more exploitation and slowly moves towards the global optimum compared to the solutions with large  $\omega$  values. To achieve this, the value of  $\omega$  will be adjusted using solution rank in the swarm, where the best solution will be ranked one while worst one will be ranked the last as calculated by Equation (5).

$$w(t) = w_{min} + (w_{max} - w_{min}) \left( \frac{R(i)}{N} \right) \quad (5)$$

where  $R(i)$  indicates the rank of the  $i^{th}$  particle (solution) in the swarm (population),  $N$  represents the swarm size.  $\omega_{min}$  and  $\omega_{max}$  are the minimum and maximum values of  $\omega$ . In Figure 2, it can be seen that the rank-based  $\omega$  is oscillating during the search process, while the linear decreasing strategy gives a value to a solution regardless its fitness value. In this figure, two solutions from the rank based PSO were used in addition to a linear based PSO to show that each solution has a different  $\omega$  values depending on its fitness value.



**Figure 2: Inertia Weight Values Over the Iterations**

From the above equation, the best solution (ranked one), will be given a value that is very close to  $\omega_{min}$ , while a big value close

to  $\omega_{max}$  will be given to the worst solution. In rank based BPSO (RBPSO), each solution is represented as a binary vector with  $N$  elements, where  $N$  is the number of features in a dataset. If a vector's element value is 1, then the corresponding feature is selected, otherwise, not selected.

### 3.2 Evaluation criterion

The second important part in designing FS tools is the evaluation criterion. The evaluation criterion examines how good the selected subset of features. In this work, the evaluation criterion is implemented as a wrapper approach. When designing a wrapper FS algorithm, two perspectives should be taken into account: the performance of the learning algorithm (e.g., classification accuracy), and the number of selected features. We therefore used a fitness function that considers both criteria as in Equation (6).

$$Fitness = \alpha \cdot Err_{rate} + \beta \frac{|n|}{|N|} \quad (6)$$

where  $Err_{rate}$  represents the classification error rate,  $|n|$  and  $|N|$  are the number of selected features and the number of original features in the dataset respectively,  $\alpha$  and  $\beta$  are the weights of the classification error rate and selection ratio,  $\alpha \in [0, 1]$  and  $\beta = (1 - \alpha)$  adopted from [23]. In this work, we use the  $k$ -NN classifier ([2]) to calculate the accuracy of the selected subset of features. From the above equation, its evident that the designed fitness function balances between the classification accuracy, which is the complement of the classification error rate, and the number of selected features in the tested solution.

## 4 EXPERIMENTAL RESULTS

In this work, Matlab is used to implement the proposed approach and all experiments were executed on a PC with Intel Core i5 processor, 2.2 GHz CPU and 4 GB of RAM. A wrapper approach-based on the  $K$ -NN classifier (where  $K = 5$  [22]) is used to generate the best reduct. In the proposed approach, each dataset is divided randomly using different seeds according to the Train/Test model; where 80% of the samples were used for training purposes, and the remaining samples for testing. The parameter settings of the proposed approach are listed in Table 1.

**Table 1: The parameters settings**

Parameter	Value
Population size	20
Number of iteration	200
Dimension	Number of features
Number of runs for each technique	30
$\alpha$ in fitness function	0.99
$\beta$ in fitness function	0.01
$w_{min}$	0.4
$w_{max}$	0.9
$k$	5 [23]

In this paper, twelve well-known datasets from the UCI data repository [12] were utilised to assess the efficacy of the proposed

approaches as in Table 2. For comparison purposes, a BPSO version that uses a linear updating strategy (see Equation 7) is implemented and tested. Moreover, the results of three well-known FS algorithms that were applied on the same datasets were adopted and a comparison with the proposed approach is conducted.

$$w(t) = w_{max} - (w_{max} - w_{min}) \frac{t}{T} \quad (7)$$

where  $w$  represents the inertia weight,  $t$  and  $T$  represent the current iteration and the max number of iterations respectively.

**Table 2: Benchmark datasets**

Dataset name	No. of classes	No. of features	No. of samples
Abalone	11	8	3842
Glass	6	9	214
Iris	3	4	150
Letter	26	16	20000
Shuttle	7	9	58000
Spambase	2	57	4601
Tae	3	5	151
Vehicle	4	18	846
Waveform	3	21	5000
Wine	3	13	178
Wisconsin	2	9	683
Yeast	9	8	1484

The results were analysed in two phases; in the first one, a comparison between the linear-based BPSO (denoted LBPSO) and the rank-based BPSO is conducted. Then, three FS approaches (i.e., PSO, GA and ACO) were obtained from the literature and compared with the proposed RBPSO.

The means of fitness values, classification accuracy, the number of selected features and the computational time for each approach were reported as shown in Table 3, Table 4 and Table 5. Inspecting the results in Table 3, it can be seen that the RBPSO clearly performs better than LBPSO in term of the classification accuracy. RBPSO was able to obtain the best results in 75% of the datasets, while LBPSO obtained the same results of RBPSO for 2 datasets and the best results were recorded to LBPSO for 3 datasets only.

From the Table 4, it can be seen that both approaches nearly have the same performance in term of the number of selected features. LBPSO obtained the best results for 7 datasets while RBPSO obtained the best results for 5 datasets. At the same time, the difference between the results is not big, and the reduction rate made by RBPSO is bigger than that by LBPSO in few datasets.

The fitness values of both approaches are also presented in Table 5. RBPSO obtained the best results in 8 datasets, while LBPSO recorded the minimum fitness values for 4 datasets only. Since the fitness function considers both classification accuracy and reduction ration, it can be concluded that the overall performance of RBPSO is better than LBPSO.

As both approaches were implemented and tested using the same environment, a comparison between them in terms of running time is also conducted. Table 6 shows the required time for each approach to converge (averaged on 30 runs). From the table, it can be observed that both approaches required nearly the same running times to converge in most of the datasets.

**Table 3: Comparison between BPSO and RBPSO in terms of classification accuracy**

Dataset	LBPSO	RBPSO
Abalone	<b>0.253</b>	0.222
Glass	0.956	<b>0.998</b>
Iris	0.966	<b>0.982</b>
Letter	<b>0.955</b>	<b>0.955</b>
Shuttle	<b>0.998</b>	0.988
Spambase	0.900	<b>0.918</b>
Tae	0.580	<b>0.599</b>
Vehicle	<b>0.727</b>	0.695
Waveform	<b>0.775</b>	<b>0.775</b>
Wine	0.254	<b>0.359</b>
Wisconsin	0.960	<b>0.966</b>
Yeast	0.522	<b>0.523</b>

**Table 4: Comparison between BPSO and RBPSO in terms of average number of selected features**

Dataset	LBPSO	RBPSO
Abalone	<b>4.22</b>	4.48
Glass	2.99	<b>1.82</b>
Iris	<b>1.12</b>	2.01
Letter	12.38	<b>12.27</b>
Shuttle	2.69	<b>2.49</b>
Spambase	<b>29.52</b>	30.29
Tae	<b>3.00</b>	3.05
Vehicle	<b>9.12</b>	9.13
Waveform	<b>13.98</b>	14.38
Wine	5.73	<b>5.03</b>
Wisconsin	4.95	<b>4.27</b>
Yeast	<b>6.14</b>	6.22

**Table 5: Comparison between BPSO and RBPSO in terms of average fitness value**

Dataset	LBPSO	RBPSO
Abalone	<b>0.729</b>	0.753
Glass	0.003	<b>0.002</b>
Iris	0.037	<b>0.007</b>
Letter	<b>0.051</b>	0.052
Shuttle	<b>0.005</b>	<b>0.005</b>
Spambase	0.093	<b>0.081</b>
Tae	0.391	<b>0.378</b>
Vehicle	<b>0.248</b>	0.271
Waveform	0.190	<b>0.189</b>
Wine	0.743	<b>0.639</b>
Wisconsin	<b>0.025</b>	0.030
Yeast	0.442	<b>0.435</b>

**Table 6: Comparison between BPSO and RBPSO in terms of average running time**

Dataset	LBPSO	RBPSO
Abalone	2.740	<b>2.700</b>
Glass	<b>0.330</b>	<b>0.330</b>
Iris	<b>0.300</b>	<b>0.300</b>
Letter	<b>33.460</b>	35.700
Shuttle	22.870	<b>22.570</b>
Spambase	<b>6.820</b>	6.910
Tae	<b>0.340</b>	0.360
Vehicle	<b>0.500</b>	<b>0.500</b>
Waveform	<b>4.370</b>	4.450
Wine	0.620	<b>0.610</b>
Wisconsin	<b>0.400</b>	<b>0.400</b>
Yeast	<b>0.900</b>	<b>0.900</b>

We now present the comparison between RBPSO and three FS algorithms that were tested on the same datasets. The results were obtained from [9] and a comparison in term of the classification accuracy is conducted because its the only measurement that was reported in that paper. Observing the results in Table 7, LBPSO and RBPSO obtained the best results in 75 % of the datasets while ACO was not able to obtain the best results in any dataset except on the Shuttle dataset where LBPSO has the same result. BGA outperformed other approaches in 25% of the datasets and BPSO outperformed other approaches in one dataset and obtained the same results as LBPSO in another dataset.

**Table 7: Comparison with other approaches from literature based on classification accuracy**

Dataset	LBPSO	RBPSO	ACO	BGA	BPSO
Abalone	<b>0.253</b>	0.222	0.238	0.241	0.241
Glass	0.956	<b>0.998</b>	0.713	0.733	0.734
Iris	0.966	<b>0.982</b>	0.963	0.967	0.965
Letter	<b>0.955</b>	<b>0.955</b>	0.806	0.837	0.825
Shuttle	<b>0.998</b>	0.988	<b>0.998</b>	0.997	<b>0.998</b>
Spambase	0.900	<b>0.918</b>	0.901	0.906	0.9
Tae	0.580	<b>0.599</b>	0.578	0.556	0.567
Vehicle	0.727	0.695	0.718	<b>0.737</b>	0.722
Waveform	0.775	0.775	0.768	0.776	<b>0.792</b>
Wine	0.254	0.359	0.938	<b>0.957</b>	0.941
Wisconsin	0.960	0.966	0.968	<b>0.975</b>	0.968
Yeast	0.522	<b>0.523</b>	0.509	0.513	0.507

From the above results, we can conclude that performance of BPSO algorithm is highly sensitive to the values of the inertia weight parameter, i.e., using different updating strategies of inertia weight parameter can highly affect the performance of BPSO algorithm. Moreover, the linear updating strategy that has been widely used in literature is not good as RBPSO. In RBPSO, different  $\omega$  value will be assigned to each solution based on its fitness value. By using this strategy, the RBPSO can effectively alternate between exploration and exploitation phases. If the solution has a

high quality, then PSO will have the chance to search its local area, otherwise, if the solution is weak, then the PSO will explore other regions in the search space hoping to find promising areas with better solutions.

## 5 CONCLUSIONS

This paper proposed a feature selection approach for data classification. The proposed approach uses the particle swarm optimisation algorithm to search for the best subset of features and the  $k$ -NN classifier as an evaluator. To improve the performance the particle swarm optimisation algorithm, we used a rank based updating strategy to adaptively change the exploration and exploitation parameter. The proposed approach was tested on twelve benchmark datasets from UCI repository and its performance was compared with three wrapper FS approaches that were tested on the same datasets. The experimental results showed that the rank based updating strategy performs better than the linear based strategy and better than the other approaches. As a future direction, we would like to apply the proposed approach on other hard optimisation problems.

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