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Identification of various control chart patterns using support vector machine and wavelet analysis

R. Russo, G. Romano *, P. Colombo

Department of Computer Services and Telecommunications Area (ASIT), Ca' Foscari University of Venice, Dorsoduro 3246, 30123 Venice, Italy

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ABSTRACT

The monitoring of production process is the basis of high-quality production. The control chart patterns (CCP) tool is one of the most efficient methods in production process monitoring. The control chart patterns are consisting of six different patterns. Each pattern indicates a special problem in the production process. The only normal pattern indicates the normal condition in the factory. The identification of these six different and independent patterns is a complicated and nonlinear classification problem. In this study, a smart system is proposed to classify these patterns by high accuracy. The proposed system uses a support vector machine (SVM) as a classifier. In support vector machine the type of kernel function and other parameters have a high effect on its performance. There are no systematic methods to determine these parameters. In the proposed method bee's algorithm is suggested to determine these parameters. Also in the pattern recognition field, the input data has a high effect on classification accuracy. In the proposed method, wavelet analysis is proposed as a feature selection section. In this section, approximation coefficients are selected as efficient input to support vector machine. To test the performance of the proposed method, the real database is used. The computer simulation results show that the proposed hybrid system has excellent performance and recognition accuracy.

1. Introduction

The production process monitoring is important problem in production of high quality products. Control chart pattern is a statistical method to monitor the production process. The control chart patterns involve six different patterns. These six different patterns are shown in Fig. 1. In Fig. 1, it is clear that these patterns are similar to each other and therefore the classification of them is very hard classification problem. In the Fig. 1, the first pattern (a) is normal pattern. In this condition the factory is in its normal state and there is no fault in production process. The second pattern (b) is cyclic pattern. The third pattern (c) is upward trend pattern, the forth pattern (d) is downward Trend pattern, the fifth pattern (e) is upward shift pattern and finally the sixth pattern (f) is downward shift. Except the normal pattern, remaining five pattern indicate the special fault in production process (Xanthopoulos and Razzaghi, 2014; Yang et al., 2015).

In each classification problem, three steps are important and must be considered carefully. The first one is classification tool. There are several classifiers such as fuzzy logic methods, artificial neural networks, and decision tree and support vector machine. Fuzzy logic methods are not flexible. In this method, the human specialist is needed to generate fuzzy rules. For this purpose, if the classification problem changes tiny, all the fuzzy rules must be changed (Zarandi et al., 2008; Gülbay and Kahraman, 2006). Another interesting classifier is artificial neural networks or ANNs. The artificial neural networks have several types such as radial basis function neural networks, probabilistic neural network, MLP neural networks, concurrent neural networks, linear vector neural networks and Elman neural networks. In issue of control chart patterns recognition, artificial neural networks have been used (Şentürk et al., 2014). Among the different types of artificial neural networks, the MLP neural network has mostly used in pattern recognition task. This type of artificial neural networks has good performance in pattern recognition problems and therefore in control chart pattern recognition issue is applied. The artificial neural networks has many advantages such as good training and don't sensitivity to input data noise. But there are some disadvantage regarding to artificial neural networks. The most important disadvantage is the related to training algorithm. All the artificial neural networks training algorithms are based on back propagation method. This training algorithm use gradient decent information. Therefore in is possible to trap in local minima and don't achieve global solution. In this training algorithm the initial solution is very important. The second disadvantage regarding to artificial neural networks is the finding the optimal configuration of them. In last works the configuration of artificial neural networks has been selected by trial and error method. This method does not have good performance and it is time consuming.

Support vector machine is classification tool that has good features in comparison with artificial neural networks (Xie and Sun, 2015). Support vector machine has good generalization feature. Also its training algorithm is more robust rather than artificial neural networks training algorithm. In this paper support vector machine (SVM) is used as classifier. In support vector machine the type of kernel function and its parameters have high impact on classification accuracy. Therefore in this study bee's algorithm is proposed as optimization algorithm to select the best parameters. In order to enhance the classification accuracy we used approximation coefficients of wavelet transform. More details regarding the wavelet analysis can be found in Dziedziech et al. (2015).

* Corresponding Author.
Email Address: gromanoal@gmail.com (G. Romano)
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The details of optimization method are presented in section two. Also the proposed classification system is presented in section three. In section 4 the computer simulation results is presented. The conclusion of paper is written in section five.

2. Bee's algorithm

In last decade several nature based optimization algorithm have been emerged. These algorithms mimic the animals and human manner in searching the best food source or location. Some of these algorithms are: Genetic algorithm (GA), particle swarm optimization (PSO) algorithm, ant colony optimization (ACO) algorithm, imperialist competitive algorithm (ICA), Cuckoo search (CS), Cuckoo optimization algorithm (COA), Bees algorithm (BA), Honey bee mating optimization (HBMO) algorithm, Artificial bee colony (ABC) and many other nature based algorithms or their modified versions (Atashpaz Gargari et al., 2008).

In each optimization algorithm, two main criteria are important: The finding of global solution vicinity or exploration and the main global solution finding exactly or extraction. Each optimization algorithm that has these two main standards will be good optimization algorithm. Many of the proposed method that has been introduced are week in one of the mentioned standards. For example the PSO algorithm has well exploration capability but doesn't have well extraction capability. In contrast, GA has very well extraction capability and week exploration capability. Also many of these optimization techniques have very operators and computational efforts.

Bees Algorithm optimization technique is an optimization algorithm that mimic the honey bee manner in food resource searching in nature. In Fig. 2, the main steps of bee's algorithm is described by details.

In bees algorithm there are several parameters and operators: (*n*) that indicates the number of scout bees, (*m*) that indicates the number of sites selected out of n visited sites, (*e*) that indicates the number of best sites out of m selected sites, (*nep*) that indicates the number of bees recruited for best e sites, (*m-e*) selected sites (*nsp*) that indicates the number of bees recruited for the other, and the primary value of patches (*ngh*) that involves site and its vicinity and stopping term. As it depicted in Fig. 3, the optimization procedure start with n bees that located randomly in defined boundaries. Before the starting the optimization method, the minimum and maximum boundaries must be determined. After the starting of the optimization procedure and placement of n bees in search space accidently, we must compute the fitness of these bees. In each optimization problem, the fitness function or target function must be defined by details and accuracy.

In next step, the bee that have high performance and fitness value, selected as elite bees. These bees placed at best locations and their vicinity may have better solutions. Thus the new bees from hive transmitted to that determined location and placed randomly near that elite bee. This strategy helps the bee's algorithm to extract the global optimum solution from all search space. The number of transmitted bees must be determined in starting of algorithm.

In next step, the non elite bees or remaining bees eliminated and the new bees are generated. These new bees placed randomly in search space. This strategy of bee's algorithm is very good for exploration of global solution vicinity. Also this strategy avoids the bee's algorithm in stacking in local minima traps. The number of the elite bees and these new randomly generated bees must be predetermined in the starting of algorithm.

This procedure is keeping on until the stop criteria are reached. In different problems, different stop criteria can be defined. In our case the maximum iteration of algorithm is determined as stop criterion.

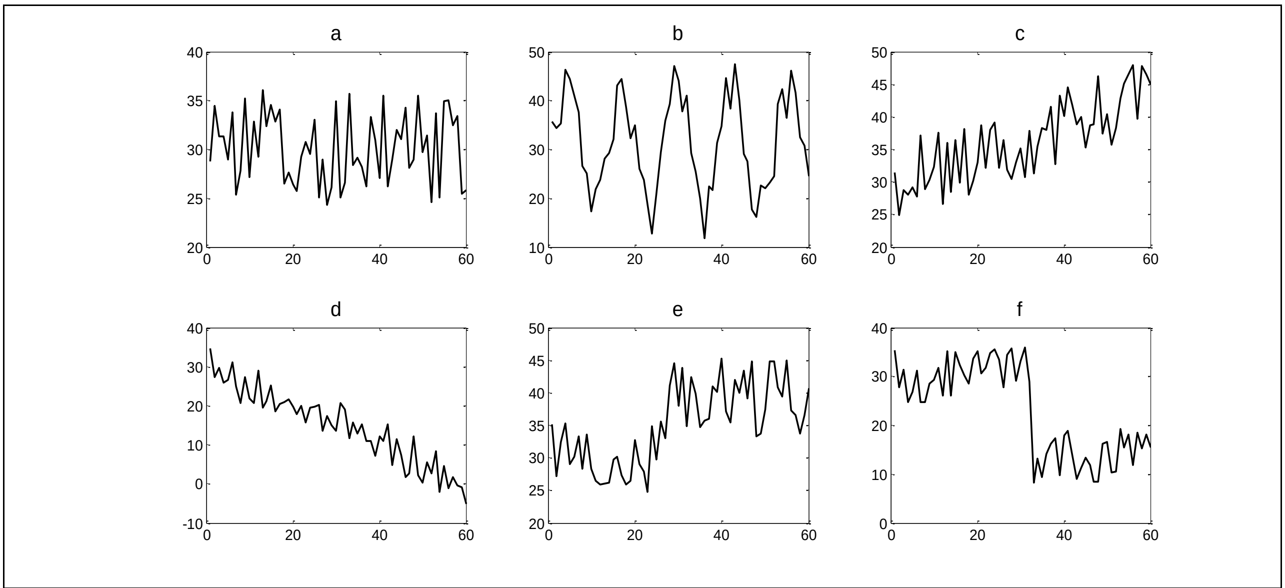

Fig. 1. Control chart patterns.

3. Proposed method

The proposed method involves three main parts. The support vector machine part, the optimization part and wavelet analysis part. In Fig. 3, the main scheme of proposed method is illustrated. The row data of CCPs is very complicated and different patterns are very similar to each other. In Fig. 4, these six different patterns are depicted simultaneously. It is clear that these patterns have overlap. Because of this overlap the classification and detection of them is very complicated and hard classification task.

1. Generate the initial population of bees in search space
2. evaluate the fitness function for each bee
3. Repeat these actions to reach stop criteria
4. Sort the bee, and select the elite bees
5. Send some bees in elite bees patches to search with more accuracy
6. Remove remaining bees and generate new bees randomly in search space
7. Check the stop conditions.
8. End

Fig. 2. Pseudo code.

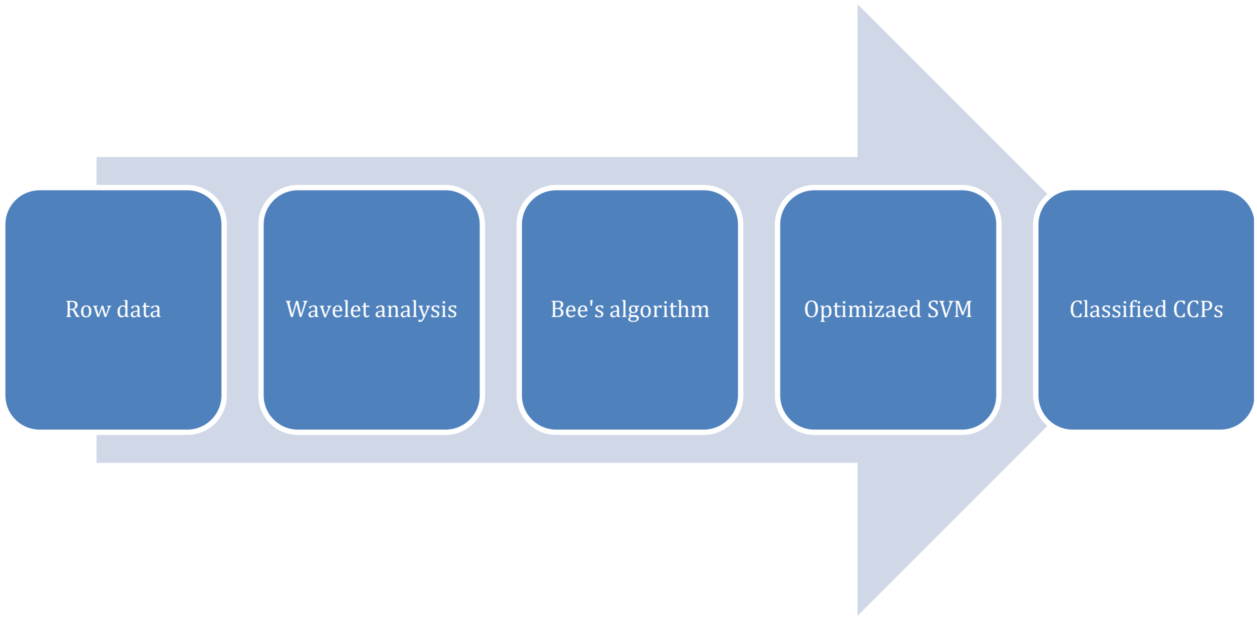

Fig 3. The scheme of proposed method.

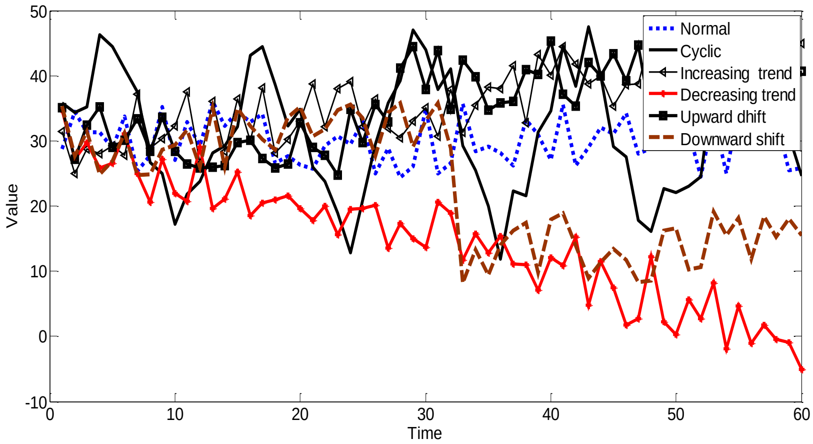

Fig 4. The CCPs and its overlap.

In the proposed method we suggested the application of wavelet analysis to improve the classification accuracy and reduce the overlap of control chart patterns. The effect of wavelet analysis on control chart patterns overlap is depicted in Figs. 5 to 10 by an example. In the Fig. 5, the increasing trend and upward shift is illustrated. In Figs. 5 to 10, the original two signal and their approximation coefficients are depicted. It is clear that the two original signals have high overlap and therefore the classification of them is difficult. In first level of decomposition, the approximation coefficients of these two signals have lower overlap. Furthermore in level two of decomposition the overlap is reduced significantly. But after the third level of decomposition the main features of signals are lose. Therefore the second level of decomposition is good for classification task.

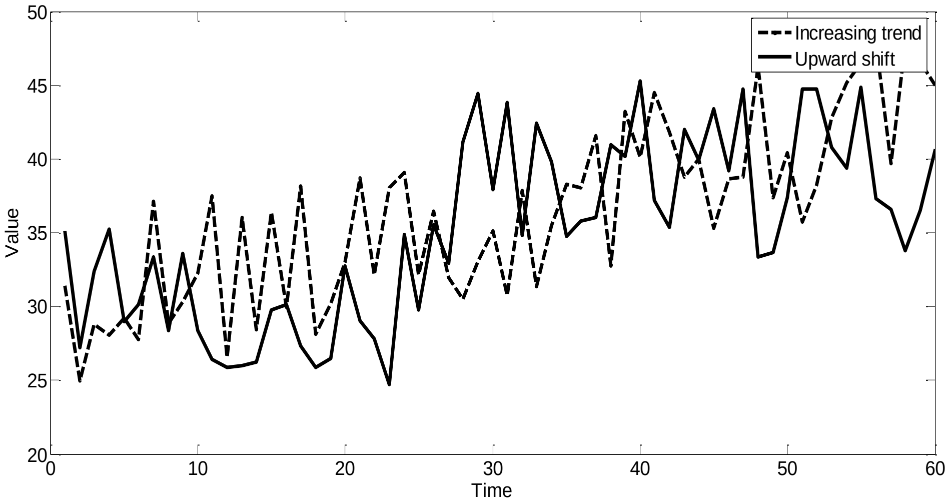

Fig. 5. The two original signal.

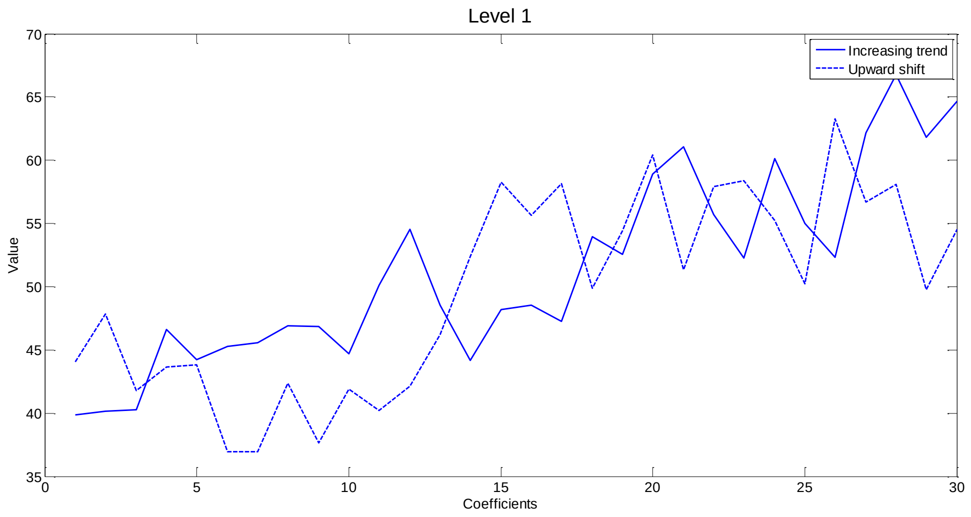

Fig 6. The level 1.

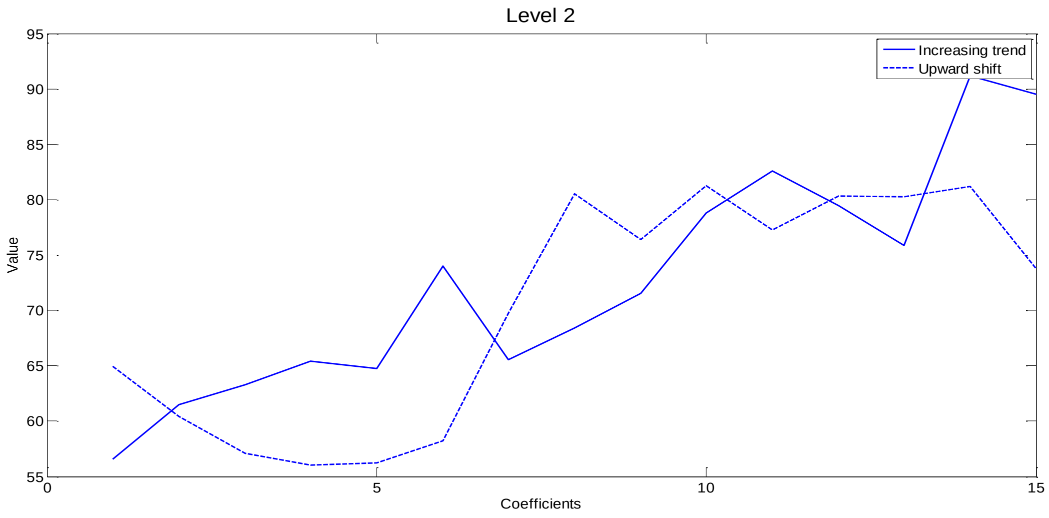

Fig 7. The level 2.

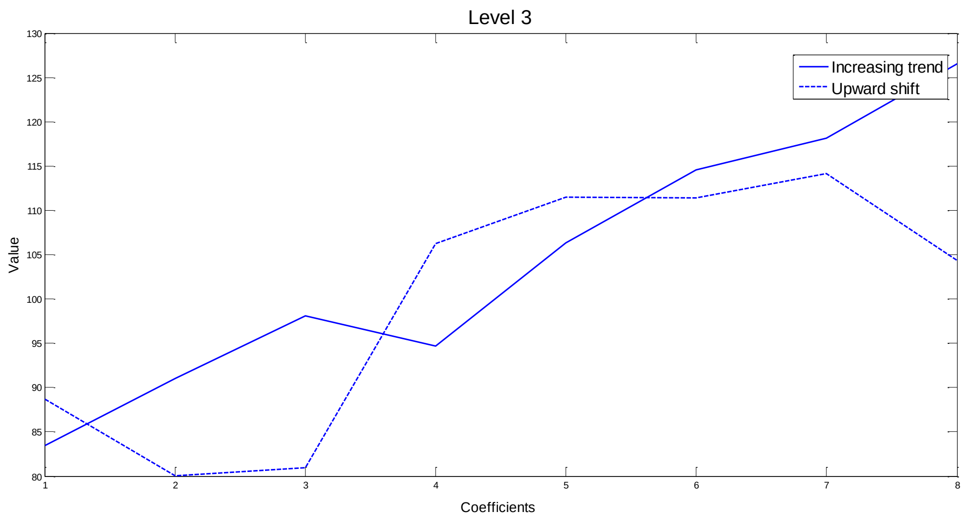

Fig 8. The level 3.

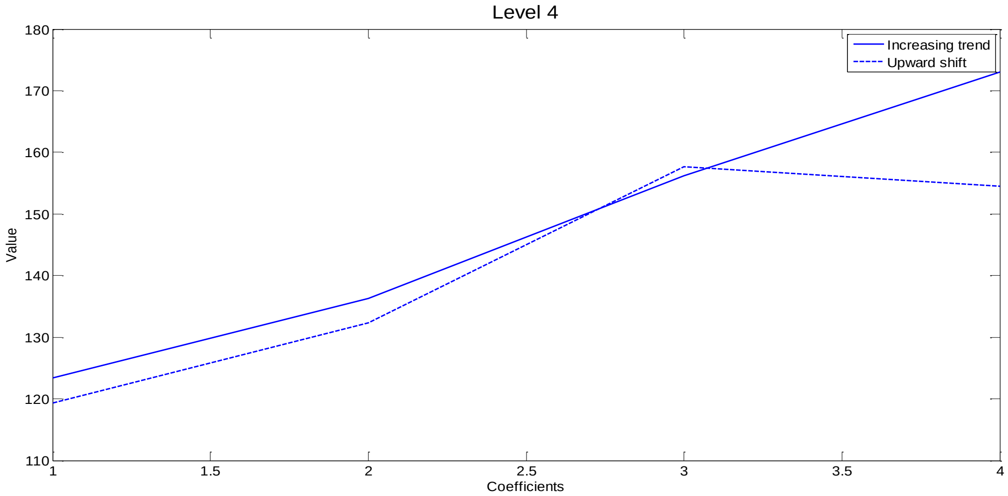

Fig 9. The level 4.

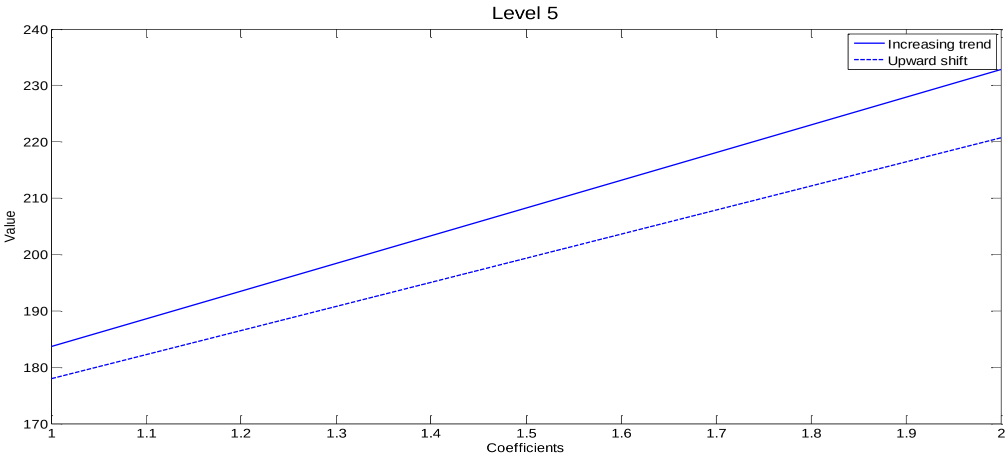

Fig 10. The level 5.

In next step of proposed system, the bee's algorithm is used as optimization algorithm to select the best kernel function and its parameters such as penalty coefficient and sigma. The simple example of bee in proposed system is illustrated in Fig. 11.

	1st variable	2nd variable	3rd variable
Sample bee:	Kernel function type	Penalty coefficient	Kernel function parameter

Fig 11. Sample bee

The main steps of proposed method are presented as below:

Step 1: Select bee's algorithm parameters
Step 2: Generate initial population of bees
Step 3: Apply wavelet transform and select approximation coefficients
Step 4: Evaluate SVM with proposed parameters by bees.
Step 5: Select elite bees
Step 6: Do local search
Step 7: Do global search
Step 8: Check stop condition. If it is satisfied, go to next step, else go to step 4.
Step 9: Finish.

4. Simulation results

In this section the performance of proposed system is evaluated. For this purpose we used real and standard database. This dataset consist of 600 signals. The share of each pattern is 100. As mentioned we used wavelet analysis to enhance the recognition accuracy. In several wavelet functions, Haar wavelet has good performance. Therefore in this paper we used this type wavelet function. In the bees algorithm the control parameters have very vital role in its speed and convergence. For this purpose we must select these parameters by accuracy. In bees algorithm the number of bees (n) is indicates the number of all the bees that spread in search space in first step. Then the soldier bees are transmitted to near the elite bee's patches. If the value of n will be high, then the simulation time will be high. Also if the value of n is low, then the probability the convergence of optimization algorithm will be low. Thus we will select the n by accuracy. Table 1 shows the bee's algorithm parameters.

Table 1
Parameters of BA.

Number of scout bees, *n*	40
Number of sites selected for neighborhood search, *m*	10
Number of best "elite" sites out of *m* selected sites, *e*	4
Number of bees recruited for best *e* sites, *nep*	4
Number of bees recruited for the other (*m*-*e*) selected sites, *nsp*	4
Number of iterations, *R*	100

In Table 2, the obtained results with row data is illustrated. It can be seen that the SVM with RBF kernel function has best recognition accuracy about 93.39%. In this state the dimension of input data is 60 and the classification time is 9 seconds. In Table 3, the effect of penalty coefficient (C) and sigma is investigated. It can be seen that these two parameters have high impact on classification accuracy. Therefore the value of these two parameters must be selected intelligently.

Table 2
The obtained results with row data.

Kernel function type	Dimension of input data	Recognition accuracy (%)	Time (Second)
Linear	60	90.21	9
Quadratic	60	91.55	8.5
RBF	60	93.39	9
Polynomial	60	90.52	9
MLP	60	92.68	9

Table 3
The effect of penalty parameter and sigma.

Row	Sigma	C	Recognition accuracy (%)
1	0.001		92.14
2	0.002		92.32
3	0.003		92.97
4	0.004	100	93.03
5	0.005		92.33
6	0.001		93.13
7	0.002		93.23
8	0.003	200	93.15
9	0.004		93.39
10	0.005		93.22
11	0.001		91.88
12	0.002		92.65
13	0.003	300	92.87
14	0.004		92.76
15	0.005		93.06

In next step we used wavelet analysis to improve the classification accuracy. The obtained results at various levels of decompositions are listed in Tables 4 to 8. In can be seen that the usage of approximation coefficients of signal improve the classification accuracy. Also the best result is obtained in level 2.

Table 4
The obtained results at level 1.

Kernel function type	Dimension of input data	Recognition accuracy (%)	Time (Second)
Linear	30	97.06	7
Quadratic	30	97.15	6.7
RBF	30	97.52	7
Polynomial	30	96.63	7
MLP	30	96.97	7

Table 5
The obtained results at level 2.

Kernel function type	Dimension of input data	Recognition accuracy (%)	Time (Second)
Linear	15	97.87	3.5
Quadratic	15	98.54	3.5
RBF	15	98.86	3.5
Polynomial	15	98.18	3.5
MLP	15	98.34	3.5

Table 6
The obtained results at level 3.

Kernel function type	Dimension of input data	Recognition accuracy (%)	Time (Second)
Linear	8	92.65	3
Quadratic	8	93.26	3
RBF	8	93.65	3
Polynomial	8	91.74	3
MLP	8	92.17	3

Table 7
The obtained results at level 4.

Kernel function type	Dimension of input data	Recognition accuracy (%)	Time (Second)
Linear	4	85.22	2.5
Quadratic	4	87.53	2.5
RBF	4	89.94	2.5
Polynomial	4	87.53	2.5
MLP	4	86.28	2.5

In next step we used bee's algorithm to find the optimum parameters of kernel function. Also the approximation coefficients are used as effective input of SVM. The obtained results are listed in Table 9. In the proposed method, we used the approximation coefficients at second level of decompositions. In this level best results are obtained. To evaluate the performance of proposed system, this system ran 10 different times. It can be seen that the proposed method can achieve the best results at each 10 independent and different runs.

Table 8
The obtained results at level 5.

Kernel function type	Dimension of input data	Recognition accuracy (%)	Time (Second)
Linear	2	**75.32**	2.5
Quadratic	2	73.76	2.5
RBF	2	75.87	2.5
Polynomial	2	75.32	2.5
MLP	2	75.18	2.5

Table 9
The performance of proposed method.

Row	*Kernel function type*	*Sigma*	*C*	*Recognition accuracy (%)*	*Time (Second)*
1	*RBF*	$\gamma = 0.0014$	400	99.58	3.5
2	*RBF*	$\gamma = 0.0014$	400	99.58	3.5
3	*RBF*	$\gamma = 0.0014$	400	99.58	3.5
4	*RBF*	$\gamma = 0.0014$	400	99.58	3.5
5	*RBF*	$\gamma = 0.0014$	400	99.58	3.5
6	*RBF*	$\gamma = 0.0014$	400	99.58	3.5
7	*RBF*	$\gamma = 0.0014$	400	99.58	3.5
8	*RBF*	$\gamma = 0.0014$	400	99.58	3.5
9	*RBF*	$\gamma = 0.0014$	400	99.58	3.5
10	*RBF*	$\gamma = 0.0014$	400	99.58	3.5

5. Conclusion

Control chart pattern recognition is one of the most efficient tools to monitoring the production process. In this issue, the high accuracy classification of these patterns is complicated problem. In this paper an intelligent approach based on SVM is proposed. The proposed approach contains three main parts. Each of these three parts have special task to enhance the classification accuracy. The effect of kernel function type, sigma and penalty parameter is investigated by detail. The simulation results show the effect of these parameters. Therefore we used bee's algorithm to select these parameters. The simulation results show that the proposed method has excellent accuracy about 99.58%.

References

Atashpaz Gargari E, Hashemzadeh F, Rajabioun R, and Lucas C (2008). Colonial competitive algorithm: a novel approach for PID controller design in MIMO distillation column process. International Journal of Intelligent Computing and Cybernetics, 1(3): 337-355. https://doi.org/10.1108/17563780810893446

Dziedziech K, Staszewski WJ, and Uhl T (2015). Wavelet-based modal analysis for time-variant systems. Mechanical Systems and Signal Processing, 50: 323-337. https://doi.org/10.1016/j.ymssp.2014.05.003

Gülbay M and Kahraman C (2006). Development of fuzzy process control charts and fuzzy unnatural pattern analyses. Computational statistics & data analysis, 51(1): 434-451. https://doi.org/10.1016/j.csda.2006.04.031

Şentürk S, Erginel N, Kaya İ, and Kahraman C (2014). Fuzzy exponentially weighted moving average control chart for univariate data with a real case application. Applied Soft Computing, 22: 1-10. https://doi.org/10.1016/j.asoc.2014.04.022

Xanthopoulos P and Razzaghi T (2014). A weighted support vector machine method for control chart pattern recognition. Computers and Industrial Engineering, 70: 134-149. https://doi.org/10.1016/j.cie.2014.01.014

Xie X and Sun S (2015). Multitask centroid twin support vector machines. Neurocomputing, 149: 1085-1091. https://doi.org/10.1016/j.neucom.2014.07.025

Yang WA, Zhou W, Liao W, and Guo Y (2015). Identification and quantification of concurrent control chart patterns using extreme-point symmetric mode decomposition and extreme learning machines. Neurocomputing, 147: 260-270. https://doi.org/10.1016/j.neucom.2014.06.068

Zarandi MF, Alaeddini A, and Turksen IB (2008). A hybrid fuzzy adaptive sampling–run rules for Shewhart control charts. Information Sciences, 178(4): 1152-1170. https://doi.org/10.1016/j.ins.2007.09.028