VPS VIBRATIONS IN PHYSICAL SYSTEMS

DOI: 10.21008/j.0860-6897.2022.2.19
Vibrations in Physical Systems, 2022, 33(2), 2022219

# Genetic Algorithms in Active Vibration Reduction Problem

**Marcin GROCHOWINA**, **Krzysztof TYBURSKI**

Uniwersytet Rzeszowski, Al Rejtana 16c, 35-959 Rzeszów

**Corresponding author:** Marcin GROCHOWINA email: gromar@ur.edu.pl

**Abstract** The design of active vibration reduction systems usually consists in selecting a control algorithm and determining the value of its settings. This article presents the results of research on the concept of using genetic algorithms to induce the settings of control systems. To test the concept, a simple pulse-excited flat bar model was selected. The vibrations were suppressed by the PID controller. Genetic algorithms with two types of crossover were tested - arithmetic and uniform. As a result, the settings for the PID controller were obtained, enabling effective reduction of vibrations in a short time.

**Keywords:** active vibration control, genetic algorithm, PID.

## 1. Introduction

Today, active vibration reduction finds many applications in various industries. The technological progress in the field of digital signal processing in recent years has developed new perspectives for the use of active circuits. The implementation of these systems is a complex issue and requires an appropriate selection of drivers and a measurement system [1, 2].

At the same time, the level of vibration is inextricably linked with the problem of noise emissions [3]. The reduction of the vibration level usually implies the reduction of the noise level, which is a significant factor burdening both industrial and everyday life. Vibration damping is therefore a method of improving human working and living conditions.

Even seemingly simple, one-dimensional models of vibration reduction systems have potentially wide practical application. Control algorithms in combination with appropriately selected actuators and dampers with controlled characteristics can be used in transport and linear drive systems [4, 5].

There are many methods of reducing vibration based on different control concepts. The simplest, single-channel feedback control systems have a sensor that measures the overall response of the mechanical system, which is transferred to the actuator after computation [6]. This method is successfully used in cases with a low level of model complexity [7].

In systems with known or measurable disturbance, the feedforward method can be used. For small changes in system parameters, a correspondingly high control efficiency is obtained, therefore most implementations were created as adaptive systems, in which the LMS (Least Mean Squares) algorithm was applied [8].

Modal control may be defined as a control that changes the eigenvalue modes of the system matrix to achieve the desired control objectives. It enables the tuning of systems with many variables and many simultaneous excitation sources. This method is based on the modal decomposition of linear systems and allows for independent control of each form of vibration independently [9].

Adaptive methods enable continuous changes of the control system parameters in response to changing model conditions. Their application, with the use of computationally efficient controllers, allow to obtain satisfactory results in unstable conditions of excitation [10].

The use of numerical methods in determining the settings of vibration reduction algorithms leads to heuristic solutions. Their task is to find the optimal solution among all possible that minimizes or maximizes the objective function. This function is used to evaluate the quality of the generated solution [11].

Genetic algorithms are optimization tools classified as artificial intelligence. They have also found widespread interest in active vibration reduction systems, e.g. for parameter optimization, sensor and actuator positions, as well as adaptive filter settings [12-14].

The use of heuristic algorithms, including genetic algorithms, is advisable, especially in tasks for which searching for solutions using analytical methods is difficult or impossible. The research presented later in this article is an introduction to the study of the use of genetic algorithms in the control systems of objects with a higher level of complexity.

## 2. Materials and methods

### 2.1. Research concept

The presented research is aimed at determining the general potential of genetic methods in active vibration reduction control systems. A simple model has therefore been adopted for which other classical methods are well known and developed. For the tests, a flat bar vibrating in one plane was used in response to a double step excitation. A PID (Proportional–Integral–Derivative) controller was used to reduce vibrations. The controller settings were selected in an evolutionary process with the use of genetic algorithms.

### 2.2. Test stand

The test stand consists of a rail along which the trolley moves. The view of the stand is shown in Fig. 1a. The trolley is powered by a DC motor switched on for a fixed time, which generates an impulse initiating vibrations of the flat bar attached to the trolley. The position of the flat bar is recorded using the Philtec RC171 laser distance sensor. The control system is implemented in the form of a software and performed on a hardware platform based on the STM32H7 Nucleo-144 microcontroller. The embedded software has been written in the C language. The actuator introducing a feedback signal to the model consists of two electromagnets interacting with neodymium magnets mounted on supports at the top of a vibrating flat bar. The time constant of the research object and the resonant frequency were determined experimentally and are equal to T = 34 s and $f_r$ = 9.6 Hz. The view of the actuator system is shown in Fig. 1b.

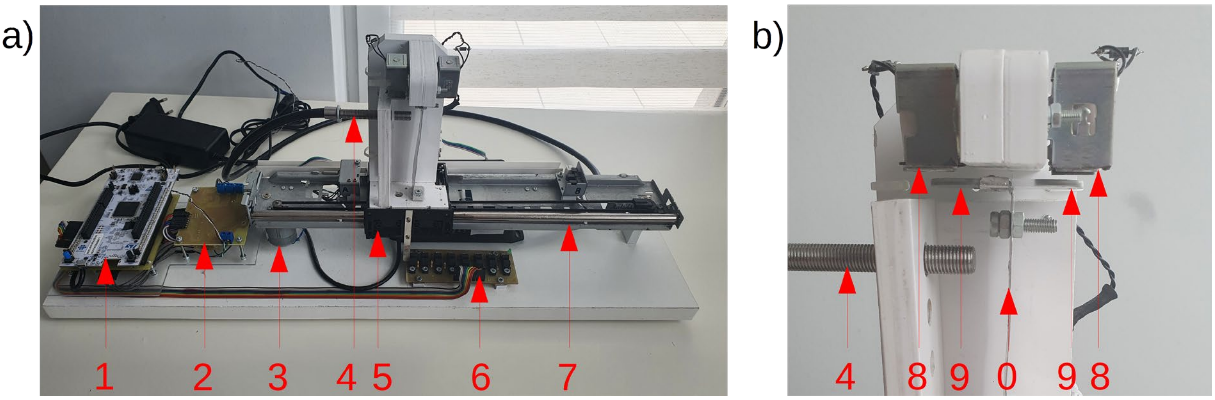


**Figure 1.** Test stand: a) general view, b) actuator view. 1 – microcontroller, 2 – H-bridge, 3 – DC motor, 4 - laser distance sensor, 5 – trolley, 6 – positioner, 7 – rail, 8 – electromagnet, 9 – magnet.

The block diagram of the test stand is presented in Fig. 2. The measurement and execution module is managed by the embedded software on the STM32H7 microcontroller. Its role is to:

- generating an impulse forcing vibrations,
- registration of the position of a flat bar,
- calculation of the excitation value of actuators,
- control of actuators.

The vibrations are forced by switching the DC motor on for 0.1s. This causes the trolley to which the flat bar is attached to shift and stop. The duration of the forcing impulse was selected experimentally to obtain the maximum vibration amplitude of the flat bar.

The flat bar position is recorded by measuring the output voltage of the Philtec RC171 laser distance sensor. The sampling rate was set at 1kS/s.

Calculation of the value of the excitation reducing vibrations is performed using the PID algorithm. The time step in the system is based on the sampling rate and is 1ms. The actuator is made of two electromagnets (Fig. 1b), the magnitude of the input calculated by the PID algorithm is transferred to the actuator by means of the PWM (Pulse-Width Modulation) signal. The sign of the forced signal determines the activation of one of the two electromagnets, on the left or on the right side of the flat bar.

The computational module implementing the genetic algorithm is implemented by a program written in Python. PID settings determined by the genetic algorithm are sent to the measurement and execution module via USART (Universal Synchronous Asynchronous Receiver-Transmitter). The measurement results in the form of the flat bar position as a function of time are sent to the program on a computer, where they constitute the basis for the assessment and selection of individuals in the genetic algorithm.

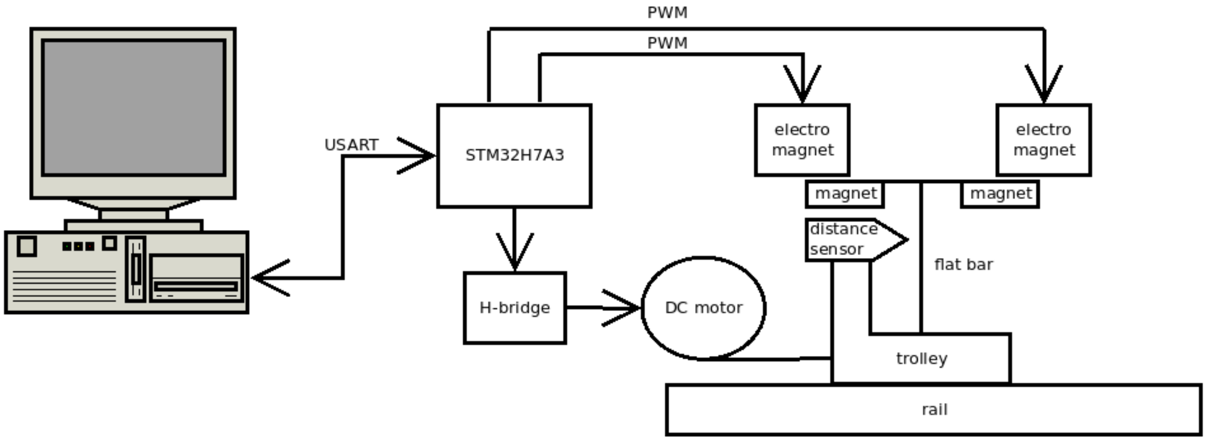


**Figure 2.** Block diagram of the test stand.

The test stand, microcontroller software implementing the PID algorithm and measurements as well as software implementing the genetic algorithm for selecting settings were made entirely and from scratch by the authors.

## 3. Genetic algorithms

The genome of the individuals used in the research is very simple. It consists of three float numbers which define the PID controller setting values. The definition of the structure containing the genome of a single individual is presented in Listing 1.

**Listing 1.** The structure containing the genome of a single individual.

```
struct individual{
   float P;
   float I;
   float D;
};
```

The adopted approach means that the genotype is synonymous with the phenotype of individuals. Two methods of crossover were chosen:

- uniform crossover, which consists in randomly selecting a pattern that determines which descendants genes are inherited from each parent, where the pattern is a binary chain, in which values 1 indicate the position (locus) in the chromosome of the first parent, and values 0 correspond positions on the chromosome of the other parent (Fig. 3).
- arithmetic crossover, which consists in calculating the value of the descendant's genes on the basis of the parents' genes according to the formula:

$$x_1' = a\, x_1 + (1-a)\, x_2, \quad x_2' = a\, x_2 + (1-a)\, x_1, \tag{1}$$

where $x_1$ and $x_2$ are the parents' vectors (chromosomes), $x_1'$ and $x_2'$ are the progeny vectors (chromosomes), and $a$ is a value between [0,1], which guarantees that the descendants will be acceptable solutions.

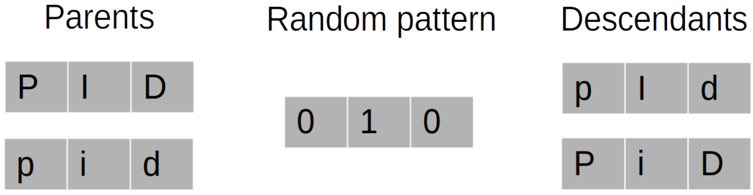


**Figure 3.** Uniform crossover scheme.

Selection is based on the ranking. A certain number of individuals with the highest ranking based on the objective function is acceptable for reproduction.

A value-uniform phenotypic mutation was used, consisting in replacing the gene from a random locus with another with a value selected randomly from a given interval. The mutation probability level was set to 0.01.

The objective function *f* is defined as the vibration stabilization time. This value is calculated on the basis of the value of the oscillation signal envelope calculated using the Hilbert transform. After lowpass filtering has been applied with a moving average filter of length $N$ = 31 according to formula:

$$y[i] = \frac{1}{N}\sum_{j=0}^{N-1} x\,[i+j], \qquad (2)$$

where $\boldsymbol{x}$[] is the input signal, $\boldsymbol{y}$[] is the output signal and $N$ is the length of the filter.

The value of the objective function determines the time after which the filtered envelope value permanently drops below 5% of the maximum value. The method of determining the value of the objective function is shown on Fig. 4.

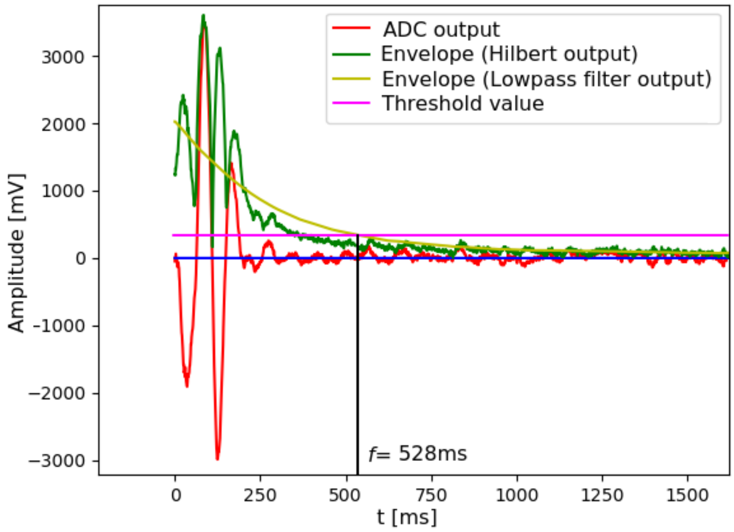


**Figure 4.** The method of determining the value of the objective function.

### 3.1. Test scheme

The genetic algorithm was used to calculate the PID controller settings. Each individual, i.e. the set of P, I and D settings, was tested. The research process was carried out according to the following algorithm:

1. Random selection of a population of 25 individuals (25 structures with P, I and D values),
2. Testing each individual:
   a) sending settings to the microcontroller,
   b) setting an impulse that forces the flat bar to vibrate,
   c) registration of the flat bar position for 5 seconds,
   d) transfer of recorded data to a computer,
   e) computing the value of the objective function,
3. selecting individuals for reproduction from the population,
4. the calculation of the new generation,
5. Repetition of points 2 - 4 25 times.

The process was repeated for arithmetic and uniform crossover.

## 4. Results and discussion

A random population of 25 individuals was used in the experiment. The evolution of the model spans 25 generations. The "0" generation was randomly selected and subjected to independent evolutionary processes using two crossing algorithms - arithmetic and uniform. Each individual was tested for 5 seconds from the moment of being forced. The time after which the vibration amplitude permanently drops below 5% of the maximum value was recorded. The summary of the regulation times in milisecounds is presented in Table 1, and their visualization in Fig. 5. Values equal to 5000 mean that the individual will not achieve the required reduction of the vibration amplitude within 5 s. The results for the best (min), worst (max)

 DOI: 10.21008/j.0860-6897.2022.2.19

individual were presented, as well as the average value of the regulation time for all individuals of a given generation.

Both the use of the arithmetic and uniform crossover operator allowed to obtain a good quality result in the first few generations. In both cases, vibration damping lasts less than 0.6 s. The best result was achieved with the use of uniform crossover - 0.514 s already in the second generation. As a result of further crossing and mutation, individuals in subsequent generations obtained slightly worse results.

Arithmetic crossover allowed to obtain a population with stable properties in the next generations. From the sixth generation on, all individuals achieve a regulation time of less than 1 s. The stability of the characteristics of the population created with the use of uniform crossover is lower. In later generations there are individuals with a low level of adaptation.

## 5. Conclusions

The use of the genetic algorithm to select the PID controller settings in the task of reducing vibrations of a flat bar can be considered successful. The generated settings made it possible to reduce the stabilization time from 24 s for an object without regulation to less than 0.6 s for an object with regulation. Both used models of crossover allowed to achieve the result at a similar level.

Arithmetic crossover allowed to obtain a stable result within the entire population, with maximum values not exceeding 1 s in subsequent generations. It can be concluded that this is the result of the specificity of the arithmetic crossover operator, which is calculated by successive generations within the space occupied by individuals of the previous generation. This approach ensures the stability of the relationships, while limiting the possibility of individuals expanding to areas beyond those that were occupied by the current population.

Uniform crossover shows less stability of results within the next generations. However, it can therefore generate individuals outside the area occupied by the current population. This has a positive effect on the genetic diversity of individuals in subsequent generations. Single, less well-adapted individuals may become progenitors of more perfect individuals in subsequent generations.

**Table 1.** Regulation time overview.

| | Crossover | | | | | |
|---|---|---|---|---|---|---|
| | Arithmetic | | | Uniform | | |
| Generation | Min [ms] | Max [ms] | Avg [ms] | Min [ms] | Max [ms] | Avg [ms] |
| 0 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 |
| 1 | 2633 | 5000 | 4719,4 | 1024 | 5000 | 4655,04 |
| 2 | 763 | 5000 | 4286,88 | 514 | 5000 | 4422,92 |
| 3 | 599 | 5000 | 4481,52 | 515 | 5000 | 3444,32 |
| 4 | 710 | 5000 | 2270,56 | 519 | 5000 | 3247,92 |
| 5 | 630 | 5000 | 1456,6 | 514 | 5000 | 2368,16 |
| 6 | 564 | 1541 | 895,44 | 518 | 5000 | 1540,92 |
| 7 | 564 | 1443 | 883,32 | 523 | 5000 | 1024,48 |
| 8 | 574 | 1645 | 890,76 | 518 | 5000 | 1105,96 |
| 9 | 566 | 1494 | 898,36 | 525 | 5000 | 942,2 |
| 10 | 566 | 1515 | 864,72 | 516 | 5000 | 859,4 |
| 11 | 569 | 1514 | 1016,12 | 556 | 712 | 641,04 |
| 12 | 567 | 1507 | 895,28 | 568 | 5000 | 867,32 |
| 13 | 562 | 1498 | 884,56 | 531 | 5000 | 848,88 |
| 14 | 562 | 1358 | 716 | 553 | 1362 | 657 |
| 15 | 555 | 1092 | 706,52 | 553 | 694 | 601,52 |
| 16 | 546 | 1064 | 704,48 | 556 | 753 | 599,24 |
| 17 | 581 | 1207 | 737,24 | 555 | 1311 | 635,8 |
| 18 | 569 | 1215 | 709,2 | 548 | 5000 | 824,28 |
| 19 | 574 | 1278 | 799,12 | 558 | 709 | 612,28 |
| 20 | 569 | 1388 | 817,08 | 551 | 718 | 599,8 |
| 21 | 570 | 1505 | 906,24 | 556 | 830 | 617,08 |
| 22 | 572 | 1366 | 790,88 | 565 | 1270 | 655,52 |
| 23 | 564 | 1364 | 766,6 | 565 | 1083 | 641 |
| 24 | 573 | 1347 | 742,72 | 565 | 788 | 612,56 |

The usefulness of the applied method in the examined case is small from the practical point of view. There are effective methods of constructing regulators with excellent parameters for objects as trivial as a vibrating flat bar. However, the conducted research has shown that the applied approach allows to determine the settings of the regulatory algorithms by inducing them with the use of genetic methods [15, 16]. These, in turn, make it possible to obtain quasi-optimal solutions of even very complex optimization problems. This means that it is highly likely that genetic algorithms can be successfully applied to induce regulators into much more complex objects such as plates and solids.

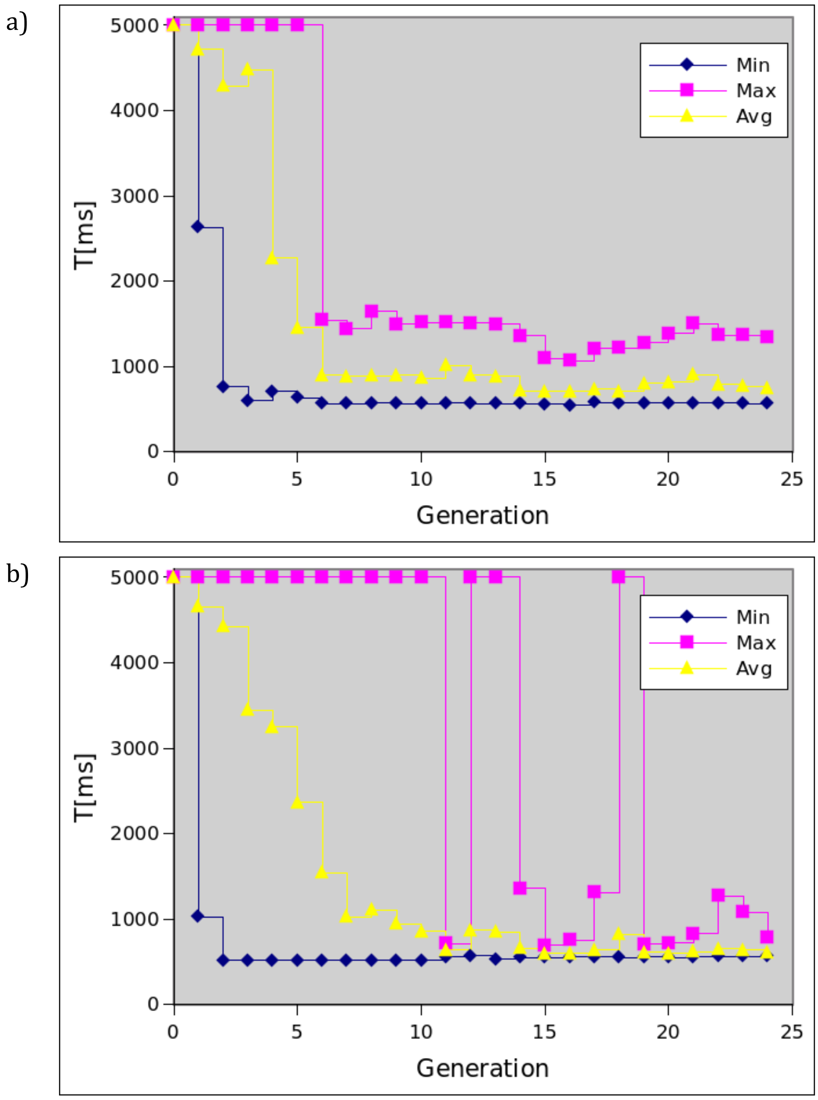


**Figure 5.** Data visualization from Table 1: a) arithmetic crossover, b) uniform crossover.

Then, although the model used was very simple, it allowed to demonstrate the possibility of using genetic algorithms in the induction of settings for regulators in the vibration reduction task. Further research will focus on the generation of parametric control functions in the form of sets of points. Such an approach will allow induction of the control function for objects, the level of complexity of which makes it impossible to design the controller in an analytical manner.

## References


1. J. Wang; Active vibration control: Design towards performance limit; Mechanical Systems and Signal Processing, 2022, 171, 108926.
2. L. Leniowska; Active methods of reducing vibrations of circular plates (in polish); University of Rzeszów, 2006.
3. M. Pawełczyk, S. Wrona, K. Mazur; Methods of Device Noise Control; In: Automatic Control, Robotics, and Information Processing, 2021 821-843, Springer, Cham.
4. B. Sapiński, J. Snamina, Ł. Jastrzębski, A. Staśkiewicz; Laboratory stand for testing self-powered vibration reduction systems; Journal of Theoretical and Applied Mechanics, 2011, 49(4), 1169-1181.
5. A. Kozieł, Ł. Jastrzębski, B. Sapiński; Advanced Prototype of an Electrical Control Unit for an MR Damper Powered by Energy Harvested from Vibrations; Energies, 2022, 15(13), 4537.
6. C.C. Fuller, S.J. Elliott, P.A. Nelson; Active control of vibration; Academic Press, 1996.

7. K. Mierzeiewski, L. Leniowska; Active vibration control of trapezoidal plate using mfc collocated sensor/actuator; In: 2018 Joint Conference-Acoustics, IEEE, 2018, 1-4.
8. Y. Kajikawa, W.S. Gan, S.M. Kuo; Recent advances on active noise control: open issues and innovative applications; APSIPA Transactions on Signal and Information Processing, 2012, 1, e3. DOI:10.1017/ATSIP.2012.4
9. C. Peukert, P. Pöhlmann, M. Merx, J. Müller, S. Ihlenfeldt, Investigation of local and modal based active vibration control strategies on the example of an elastic system; Journal of Machine Engineering, 2019, 19(2), 32-45. DOI: 10.5604/01.3001.0013.2222
10. L. Leniowska, M. Grochowina, M. Sierżęga, B. Hołota; An Adaptive Method for Reducing Vibrations of Circular Plates with Recursive Identification; Applied Sciences, 2022, 12(5), 2723.
11. N. Kokash; An introduction to heuristic algorithms; Department of Informatics and Telecommunications, University of Trento, Italy, 2008, 1-8.
12. K. Bendine, F.B. Boukhoulda, B. Haddag, M. Nouari; Active vibration control of composite plate with optimal placement of piezoelectric patches; Mechanics of Advanced Materials and Structures, 2019, 26(4), 341-349.
13. M.H. Awadalla; Spiking neural network and bull genetic algorithm for active vibration control; International Journal of Intelligent Systems and Applications, 2018, 10(2), 17.
14. C.K.H. Lee; A review of applications of genetic algorithms in operations management; Engineering Applications of Artificial Intelligence, 2018, 76, 1-12.
15. A. Lambora, K. Gupta, K. Chopra; Genetic algorithm-A literature review; In: 2019 international conference on machine learning, big data, cloud and parallel computing (COMITCon), 2019, 380-384.
16. S. Katoch, S. S. Chauhan, V. Kumar; A review on genetic algorithm: past, present, and future; Multimedia Tools and Applications, 2021, 80(5), 8091-8126.