CONCORDIA UNIVERSITY

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

ENCS 6181 – Optimization Techniques

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Team - 9

Deployment of sensor at optimized location for analyzing Tsunami waves using FA-PS Method.

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1. ABSTRACT:

Tsunamis are one of the natural disasters which cause massive loss to mankind. Pressure sensors are placed in the water to analyze tsunami waves by measuring changes in water depth and speed of the water stream, as the tsunami passes overheads. Deploying the sensor in the right location would help in faster analysis and alerts of tsunamis to the people. The firefly algorithm is one of the new meta-heuristic algorithms for optimization problems. The algorithm is inspired by the flashing behavior of fireflies. From this algorithm, the optimized sensor placement will be obtained, by taking different locations from latitudes and longitudes. The objective function is assigned by the speed and depth of the wave height. From the journal, the conventional FA results in an imbalanced relationship between exploration and exploitation. This imbalanced relationship causes the incapability of FA to find the most optimum values at the termination stage. This is resolved by introducing a pattern search method at the termination stage which gives the balanced relationship between exploration and exploitation and helps in finding the most optimum location to deploy the sensor in-order to analyze the tsunami waves.

2. INTRODUCTION:

2.1 Optimization:

An optimization problem is a problem of finding values for the variables of a function to optimize the function. Even though there are many solution methods, there are many problems which need special attention and are hard to solve using the deterministic solution methods. Meta-heuristic algorithms are optimization algorithms which try to improve the quality of solution members iteratively with some randomness properties. One such algorithm is Firefly algorithm.

2.2 Firefly Algorithm:

The reason behind choosing the firefly algorithm apart from all other optimization algorithms is it is efficient and an easy to implement algorithm. It is also suitable for parallel implementation The firefly algorithm is a swarm based meta-heuristic algorithm that was introduced by Yang. The algorithm mimics how fireflies interact using flashing lights. The algorithm mimics how fireflies interact using their flashing lights. The algorithm assumes that all fireflies are unisex, which means any firefly can be attracted to a brighter firefly. The brightness is calculated

In the algorithm, a randomly generated feasible solution, called fireflies, will be assigned with a light intensity based on their performance in the objective function. This intensity will be used to compute the brightness of the firefly, which is directly proportional to its light intensity.

For minimization problems, a solution with smallest functional value will be assigned with highest light intensity. Once the intensity or brightness of the solutions is assigned, each firefly will follow fireflies with better intensity. For the brightest firefly, it will perform a local search by randomly moving in its neighbourhood. Hence for two fireflies, if firefly j is brighter than firefly I, then firefly I will move towards firefly j, therefore the equation based on the attraction of brighter firefly is given by :

$$x_i := x_i + \underbrace{\beta_0 e^{-\gamma r_{ij}^2}}_{=\beta}(x_j - x_i) + \alpha(\varepsilon(\,) - 0.5)$$

2.3 Occurrence of Tsunami Waves:

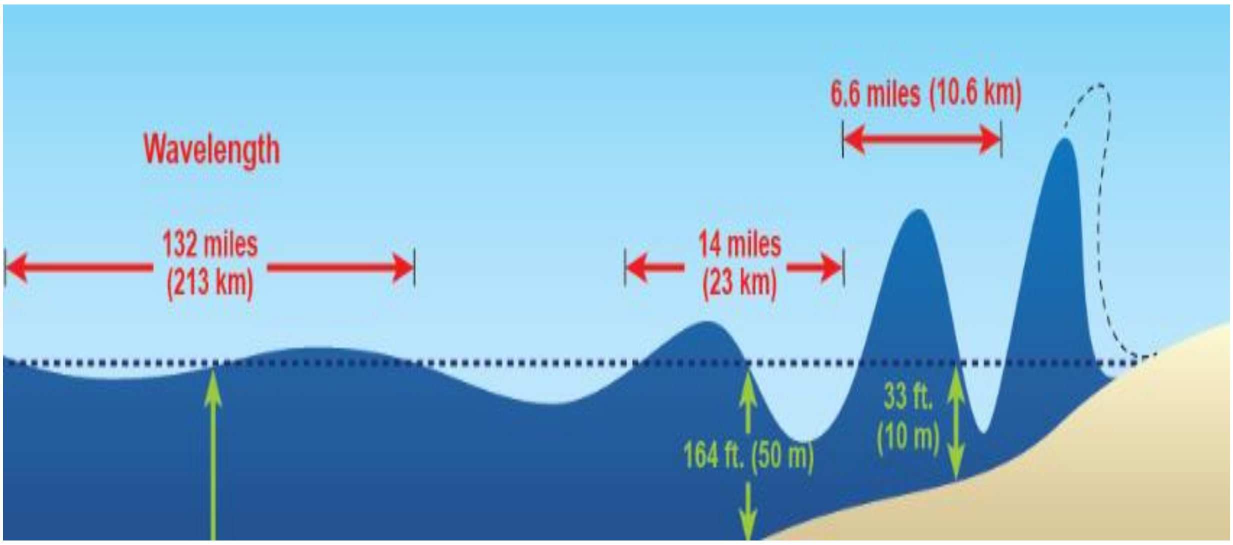
[2] A tsunami is a series of extremely long waves caused by a large and sudden displacement of the ocean, usually the result of an earthquake below or near the ocean floor. This force creates waves that radiate outward in all directions away from their source, sometimes crossing entire ocean basins. Once a tsunami forms, its speed depends on the depth of the ocean. In the deep ocean, a tsunami can move as fast as a jet plane, over 500 mph, and its wavelength, the distance from crest to crest, may be hundreds of miles. Mariners at sea will not normally notice a tsunami as it passes beneath them; in deep water, (DART) systems which contains pressure sensor, located in the deep ocean, are able to detect small changes in sea-level height and transmit this information to tsunami warning centers. This information is taken to find the optimized location for the sensor to be deployed.

3. STATEMENT OF THE PROBLEM:

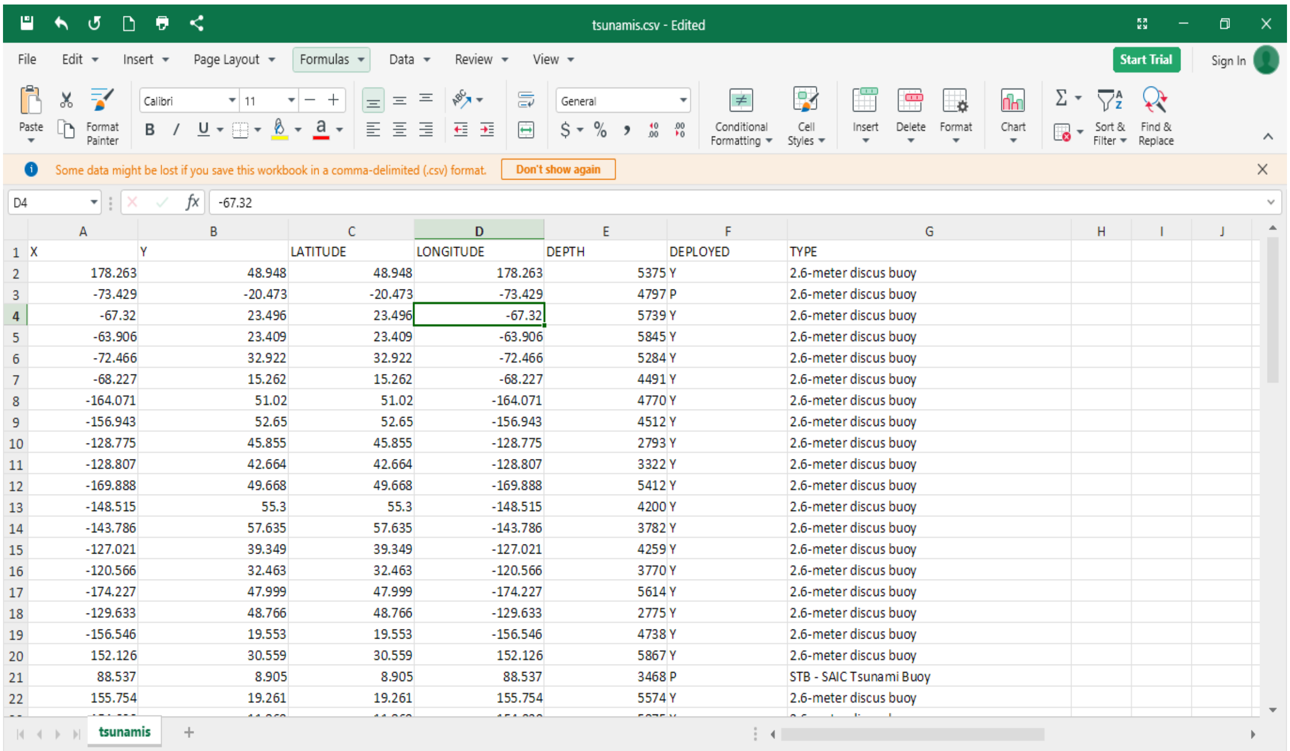
The world's worst natural disasters that can hit a country is Tsunami. The tsunami effects range from destruction and damage, death, injury, millions of dollars in financial loss, and long lasting psychological problems for the inhabitants of the region. Deploying sensor at an optimized location would help in accurate analysis of tsunami waves and send alerts and warnings to people beforehand to overcome massive destructions caused by tsunami.

4. SPECIFICATIONS:

The major parts of a wave are the crest (the highest point), the trough (the lowest point), the height (distance from trough to crest), the wavelength (distance between identical points on two waves, typically crest to crest) and period (the time it takes for the same spot on two consecutive waves to pass the same point)
Tsunami propagates through the entire depth of the ocean, from the surface of the floor. They move at great speed with tremendous energy. The speed of tsunami depends on the depth of the water it is traveling through. The deeper the water results in faster the tsunami. On an average in deep ocean the tsunami waves can move over a speed of 100mph (120 km/h). At the shore, most tsunamis slows down, approximately 20 to 30 mph (30 to 50 km/h). Tsunami speeds can be calculated:



The above picture and the below dataset is taken from National Oceanic and Atmospheric Administration (NOAA).



X	Y	LATITUDE	LONGITUDE	DEPTH	DEPLOYED	TYPE
178.263	48.948	48.948	178.263	5375	Y	2.6-meter discus buoy
-73.429	-20.473	-20.473	-73.429	4797	P	2.6-meter discus buoy
-67.32	23.496	23.496	-67.32	5739	Y	2.6-meter discus buoy
-63.906	23.409	23.409	-63.906	5845	Y	2.6-meter discus buoy
-72.466	32.922	32.922	-72.466	5284	Y	2.6-meter discus buoy
-68.227	15.262	15.262	-68.227	4491	Y	2.6-meter discus buoy
-164.071	51.02	51.02	-164.071	4770	Y	2.6-meter discus buoy
-156.943	52.65	52.65	-156.943	4512	Y	2.6-meter discus buoy
-128.775	45.855	45.855	-128.775	2793	Y	2.6-meter discus buoy
-128.807	42.664	42.664	-128.807	3322	Y	2.6-meter discus buoy
-169.888	49.668	49.668	-169.888	5412	Y	2.6-meter discus buoy
-148.515	55.3	55.3	-148.515	4200	Y	2.6-meter discus buoy
-143.786	57.635	57.635	-143.786	3782	Y	2.6-meter discus buoy
-127.021	39.349	39.349	-127.021	4259	Y	2.6-meter discus buoy
-120.566	32.463	32.463	-120.566	3770	Y	2.6-meter discus buoy
-174.227	47.999	47.999	-174.227	5614	Y	2.6-meter discus buoy
-129.633	48.766	48.766	-129.633	2775	Y	2.6-meter discus buoy
-156.546	19.553	19.553	-156.546	4738	Y	2.6-meter discus buoy
152.126	30.559	30.559	152.126	5867	Y	2.6-meter discus buoy
88.537	8.905	8.905	88.537	3468	P	STB - SAIC Tsunami Buoy
155.754	19.261	19.261	155.754	5574	Y	2.6-meter discus buoy

In this dataset the predetermined dataset is taken based on the locations (longitudes and latitudes) of the previously occurred tsunamis and its depth and wavelength and interesting thing is there has been data about whether the sensor was deployed or not. In our problem we are using this dataset to determine constraints and objective function is based on banana function equation.

$$f(\mathbf{x}) = \sum_{i=1}^{d-1} \left[100(x_{i+1} - x_i^2)^2 + (x_i - 1)^2\right]$$

X = [1,3] & X is Wavelength(meters)

x(1)*x(2) + x(1) - x(2) + 1.5 <= 0 (Non-linear Constraints)

10 - x(1)*x(2) <= 0 (Non-linear Constraints)

0 < = x(1) < = 1 (Bounds)

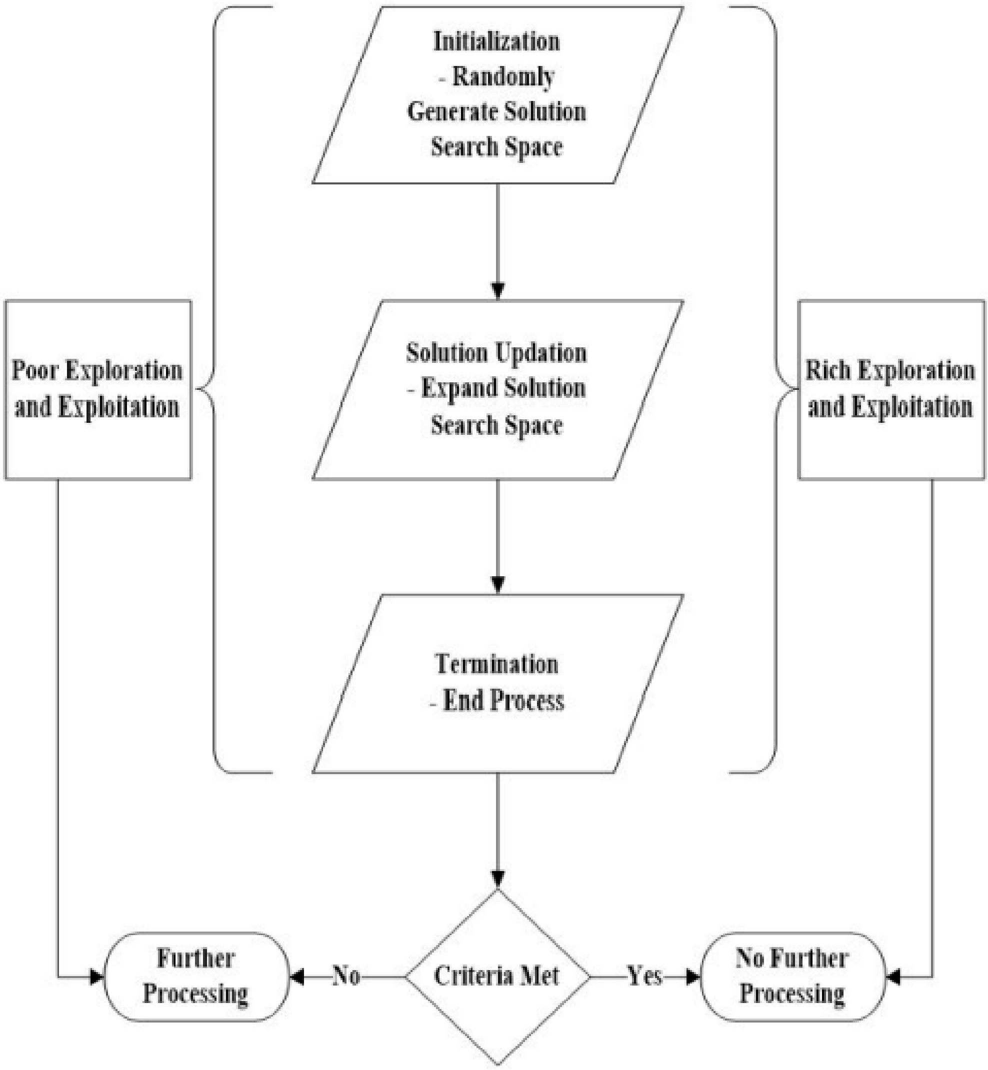
1 < = x(2) < = 13 (Bounds)

From the dataset we can understand that if a tsunami occurs then at the wavelength it rises we can predict the rate of propagation and its massive destruction. To be precise for example, at the rate of 100 mph mentioned above, a tsunami will travel Alaska's island to Hawaii in 4 hours and from Portugal coast to North Carolina in 8 hours which is massive. Finally based on the objective function and non-linear constraints we can find the optimized location the sensor needed to be deployed in the ocean bed in-order to give accurate information about tsunami waves.

5. METHODOLOGY:

Firefly Algorithm-Pattern search Method(FA-PS):

From the journal, we have used the Firefly algorithm based pattern search method in-order to find the optimized sensor deployment location. Basic operation of all iterative algorithm consist of three major stages namely the algorithm initialization, updating the solutions and termination of the algorithm. During the initialization stage. Problem context. solution search space is defined by randomly generating the solution search space by keeping in consideration the dependent and independent variables of the optimization problem and the dependent values of optimization function. During each iteration of the algorithm, the solution search space generated in the initialization stage is updated to consider more values worth contribution towards finding the most optimal solution. In the termination stage, the algorithm is terminated in either of two conditions. Firstly, the required optimal value of the optimization function is obtained. Secondly, the maximum number of iteration is reached. If the most optimal value of the optimization function is obtained, the approach is said to be successful and no further processing is required. But, if the maximum no of iteration is reached and the algorithm terminates without getting the most optimal value, then the algorithm is suffered from poor exploration or poor exploitation of the solution search space during the initialization or solution search space updating stage. The complete description of this context is given by below flowchart.



The exploitation and exploration of the solution search space can be improved at that different stages but that is a complicated procedure as the internal working mechanism of iterative algorithms is complex process. If the optimum value is not reached in iterations then the issue has been resolved by simply embedding the PS at the termination stage of standard FA which takes the solutions from the standard algorithm and improves the exploration and exploitation of the solution search space that further optimizes the values obtained.

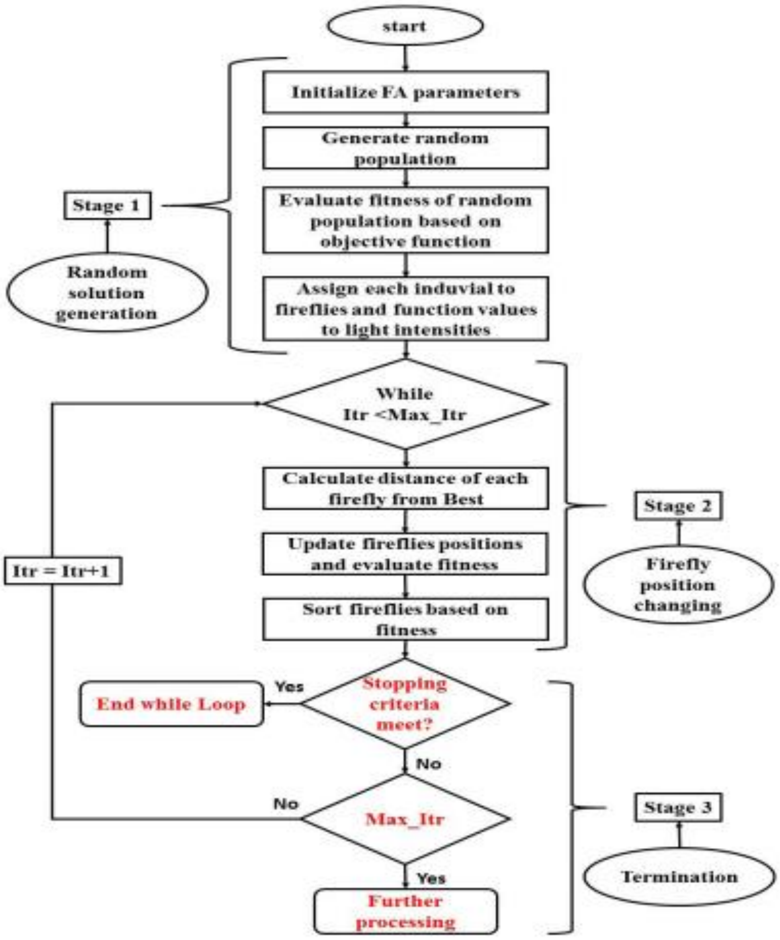
- **Conventional Firefly Algorithm:**

FA is one of the recently developed SI algorithm used for solving various types of optimization problems. Like other optimization problems, the FA consists of three major stages when applied for solving problems of optimization nature; the initialization stage, the firefly position changing stage and the termination stage.

[1] In the initialization stage, the solution search space is randomly generated by keeping in consideration the variables used in the optimization function and the associated value of the optimization function. In the firefly position changing stage, the positions of fireflies are updated by using a factor known as randomization factor for discovering more solutions of the problem been targeted. In the termination stage, the algorithm terminates.

In the position change stage, the randomness in the initial solution space may create imbalanced relationship between exploration and exploitation of the solution search space leading to slower local and global convergence rates of the algorithm resulting in degraded solution quality. The randomization factor in firefly position changing stage decides the movements of the fireflies. If this value is not handled very carefully, it may lead to degraded solution quality of the problem.

During the termination stage, the optimized values obtained depend upon the relationship between exploration and exploitation of the solution search space established in the initialization and firefly position changing stage. If the algorithm terminates and the values obtained are the most optimal values, then there is no need of further processing.



➢ FA Algorithm :

Initialization of FA parameters
- Total number of fireflies in the algorithm: **No**
- Number of generations: **Max**
- The values of β_o, γ, α, ϵ
- Put the generation counter i=0

Generate initial population of fireflies "Pt" using $x_1, x_2, x_3 \ldots, x_n$ of Equation 6,…, Equation 19 representing light intensity values
Evaluate fitness values "FV" of Equation 6,…, Equation 19 using randomly generated values of $x_1, x_2, x_3 \ldots, x_n$
Sort the fireflies according to the values of fitness function "FV"
Find the best firefly from the sorted fireflies
Put $i = 0$
While (i<Max)
- {
- STEP1: Calculate the Euclidean distance r_{ij} of each firefly from all fireflies using Equation 4
- STEP2: Calculate the attractiveness β of each firefly for other fireflies using Equation 3
- STEP3: Update position Xi of each firefly using Equation 5
- STEP4: Evaluate new "FV" values associated with each firefly
- STEP5: Sort and rank the updated population for values of "FV"
- STEP6: i=i+1
- }

Return the best solution

Limitations of FA:

[1] The first limitation of standard FA is the initial random solution generation at the initialization stage. This randomness in the initialization stage leads to imbalanced relationship between the exploration and exploitation of the solution search space that ultimately degrades the solution quality. A third major drawback is its termination without being able to get the most optimal solution of the optimization problem.

- **Pattern Search Algorithm:**

Pattern search is a kind of optimization algorithm having strong capability of solving various kinds of optimization problems where other standard optimization algorithms face failure in finding the most optimal solution. Its easy implementation, conceptual simplicity and computational efficiency make it more applicable than the other optimization techniques. The basic operations of the pattern search consist of few technical steps. First of all, the mesh size (MS), the expansion factor (EF), the contraction factor (CF) and the maximum number of iterations (Maxitr) is specified. After specifying these parameters, the starting points of PS are set initially or these points are taken form some other algorithms.

In our work, these points have been taken form the standard FA. Using these starting points, the mesh points and pattern vectors are created. The mesh points are used to evaluate the values of objective function to be optimized. In order to check the optimized function values, the mesh points values obtained are checked. If the obtained values obtained are better than the previous values, it means the algorithm is going in right direction, the mesh point's values are expanded and the procedure proceeds. If the values obtained are not better than the previous values, it means the mesh size needs to be contracted and new points are set as starting points. This procedure continues until the termination stages reaches or the maximum number of iteration reaches. The pattern search algorithm has been applied for solving various types of optimization problems.

Initialization of parameters
- MS, EF, CF, Maxitr

Set initial mesh points "MP" using $x_1, x_2, x_3 \ldots, x_n$ of Equation 6,..., Equation 19
Evaluate fitness values "FV" of Equation 6,..., Equation 19 using values of $x_1, x_2, x_3 \ldots, x_n$ from FA
Put $i = 0$
While (i<Maxitr)
- {
- IF($FV_{i+1} < F_i$) // for minimization functions
- Expand "MS"
- ELSE
- Contract "MS"
- Set new "MP" using $x_1, x_2, x_3 \ldots, x_n$ of Equation 6,..., Equation 19
- END IF
- IF($FV_{i+1} > F_i$) // for maximization functions
- Expand "MS"
- ELSE
- Contract "MS"
- Set new "MP" using $x_1, x_2, x_3 \ldots, x_n$ of Equation 6,7, 8 and 19
- END IF
- }

Return the result

- **FA-PS Algorithm**:

[1] For our work we have chosen this algorithm based on the limitations of conventional firefly algorithm. This algorithm would have balanced relationship between exploration and exploitation.

In the basic operation of standard FA, If the algorithm terminates after getting the required optimal value, then the approach is said to be successful in achieving the target goal and there is no further processing required. If the algorithm terminates after the maximum number of iteration reaches and the value obtained is not the most optimal value, then the number of iterations can be increased. Even after increasing the number of iterations, the value obtained is not the most optimal value, and then some other technique can be applied to get the most optimal value or at least the value better than the value obtained by standard FA in its maximum iterations.

If the maximum number of generations of firefly algorithm reaches and the solution obtained is not the most optimal solution, then the pattern search algorithm is introduced to further enhance the exploration and exploitation of the solution search space to obtain the most optimal solution or at least the solution better than the so far obtained solution.

Pattern search is a kind of optimization algorithm having strong capability of solving various kinds of optimization problems where other standard optimization algorithms face failure in finding the most optimal solution. Its easy implementation, conceptual simplicity and computational efficiency make it more applicable than the other optimization techniques. In the proposed approach, pattern search (PS) has been applied to target this issue and to improve the results obtained by standard FA. The PS takes the value obtained by standard FA as starting point and performs further processing to get the minimum or maximum value of the minimization or maximization functions, respectively.

➢ FA_PS Algorithm

Initialization of FA parameters
- Total number of fireflies in the algorithm: **No**
- Number of generations: **Max**
- The values of β_o, γ, α, ϵ
- Put the generation counter i=0
- Mesh size: **MS**
- Expansion Factor: **EF**
- Contraction Factor **CF**
- Maximum number of iteration in PS: **Maxitr**

Generate random initial solutions of fireflies "Pt" using $x_1, x_2, x_3 \ldots, x_n$ of Equation 6,..., Equation 19 representing light intensity values
Evaluate fitness values "FV" of Equation 6,..., Equation 19 using randomly generated values of $X1, X2, X3, \ldots, Xn$
Sort the fireflies according to the values of fitness function "FV"
Find the best firefly from the sorted fireflies
Put $i = 0$
While (i<Max)
- {
- STEP1: Calculate the Euclidean distance r_{ij} of each firefly from all fireflies using Equation 4
- STEP2: Calculate the attractiveness β of each firefly for other fireflies using Equation 3
- STEP3: Update position Xi of each firefly using Equation 5
- STEP4: Evaluate new "FV" values associated with each firefly
- STEP5: Sort and rank the updated population for values of "FV"
- STEP6: i=i+1
- }

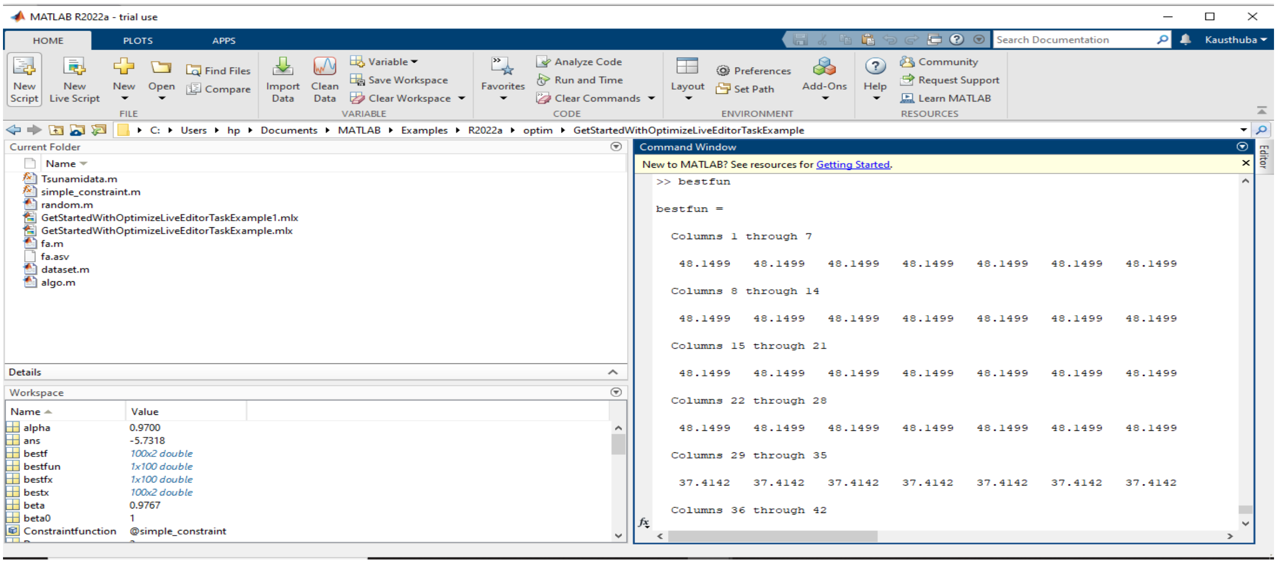
Assign the parameter of FA to PS
Set initial mesh points "MP" using $x_1, x_2, x_3 \ldots, x_n$ of Equation 6,..., Equation 19
Evaluate fitness values "FV" of Equation 6,..., Equation 19 using values of $x_1, x_2, x_3 \ldots, x_n$ from FA
Put $i = 0$
While (i<Maxitr)
- {
- IF($FV_{i+1} < F_i$) // for minimization functions
- Expand "MS"
- ELSE
- Contract "MS"
- Set new "MP" using $x_1, x_2, x_3 \ldots, x_n$ of Equation 6,..., Equation 19
- END IF
- IF($FV_{i+1} > F_i$) // for maximization functions
- Expand "MS"
- ELSE
- Contract "MS"
- Set new "MP" using $x_1, x_2, x_3 \ldots, x_n$ of Equation 6,7, 8 and 19
- END IF
- }

Return the result

6. ANALYSIS:

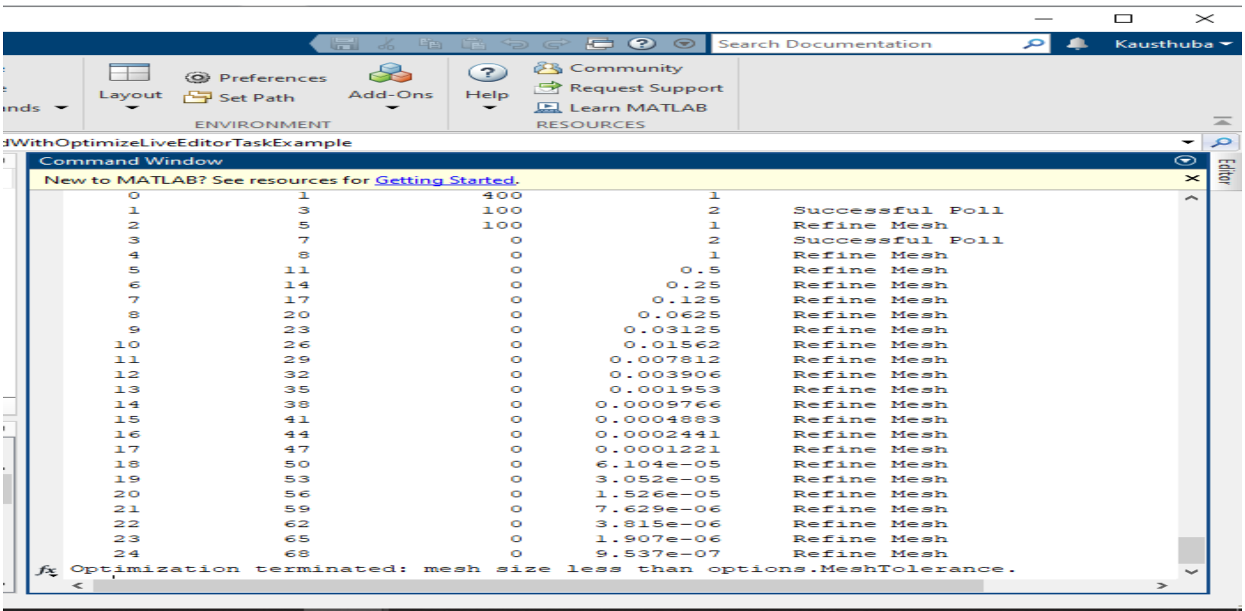
The performance of conventional firefly algorithm, Pattern search and FA-PS method is evaluated.

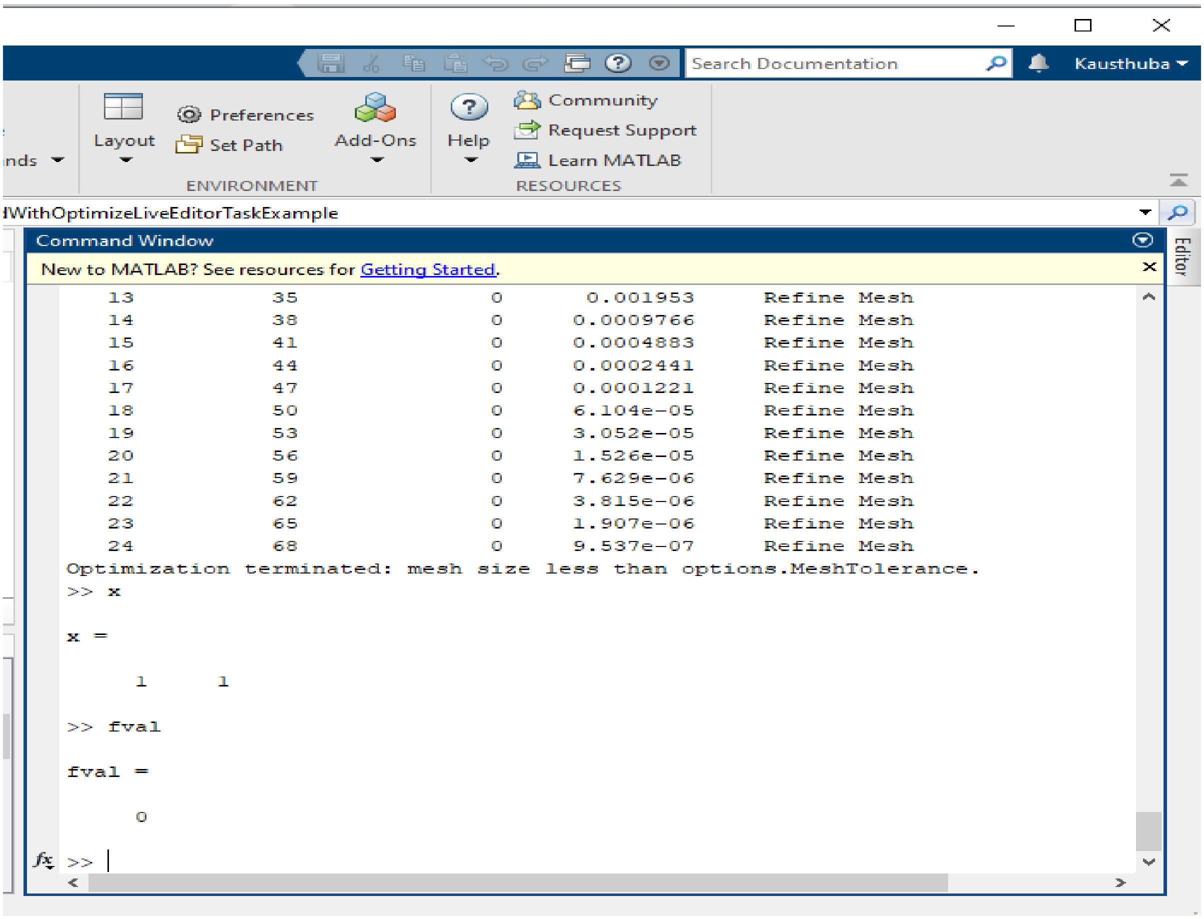
Conventional Firefly Algorithm:



Optimal value from Conventional firefly algorithm is obtained but the optimal value is obtained after the termination stage of the algorithm which caused low exploration.

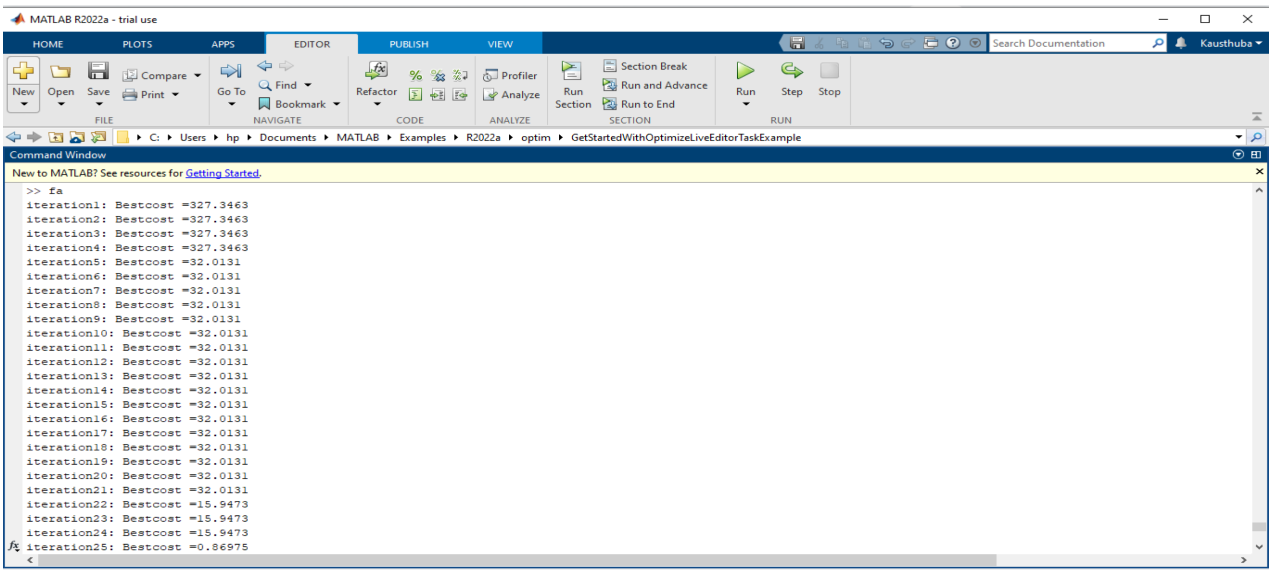
Pattern Search Algorithm:

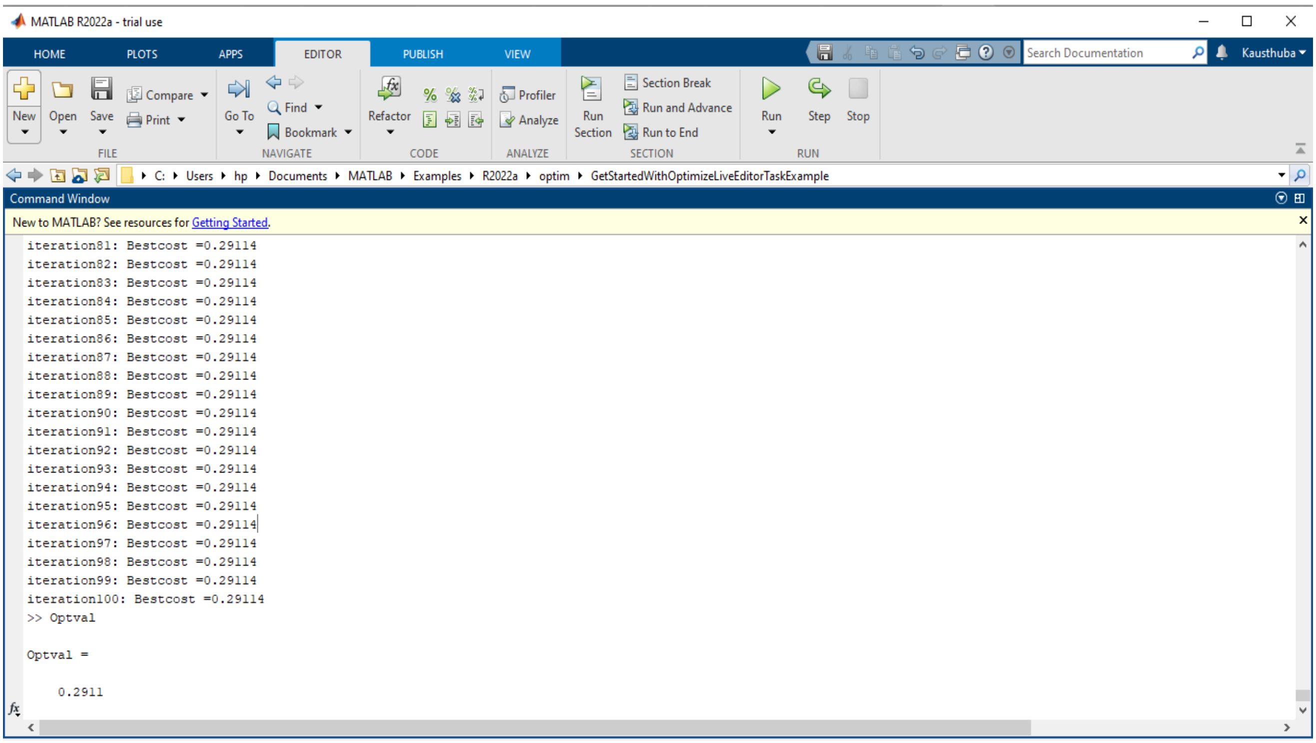




Optimal value is obtained but it is more compared to conventional firefly algorithm. Pattern search methods is difficult to execute and, it is an extremely slow method. It requires a bigger dataset to acquire enhanced accuracy.

FA-PS Algorithm:

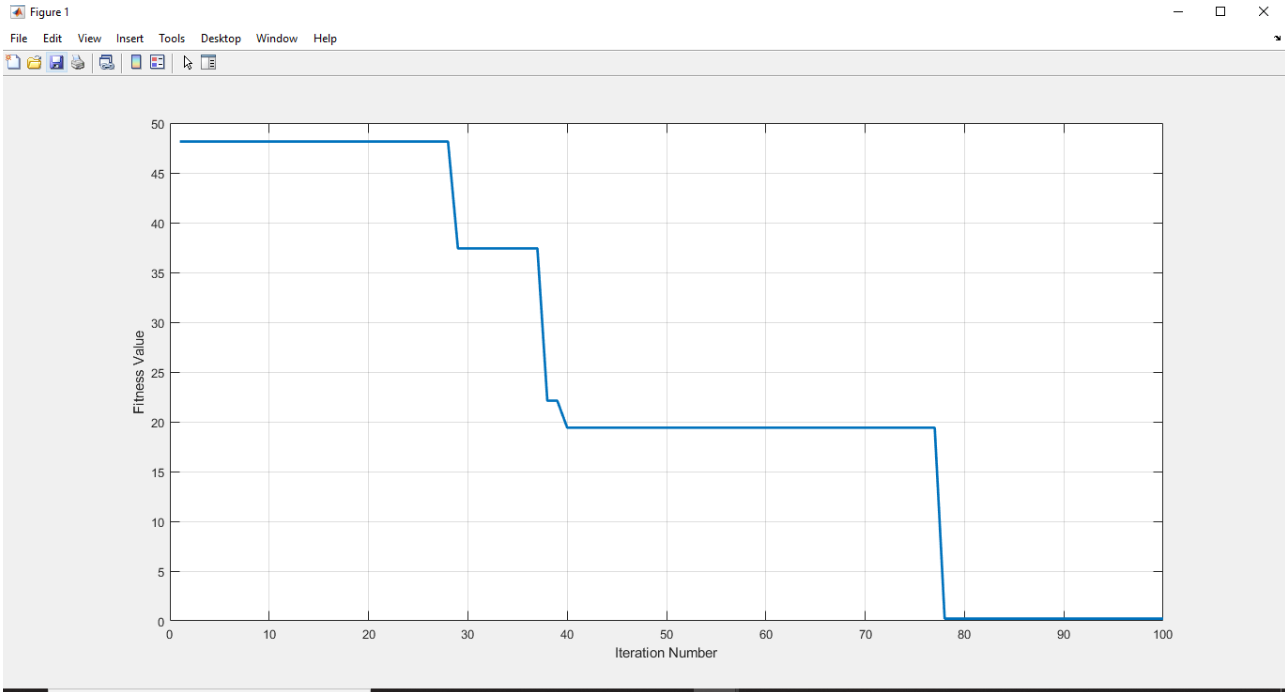




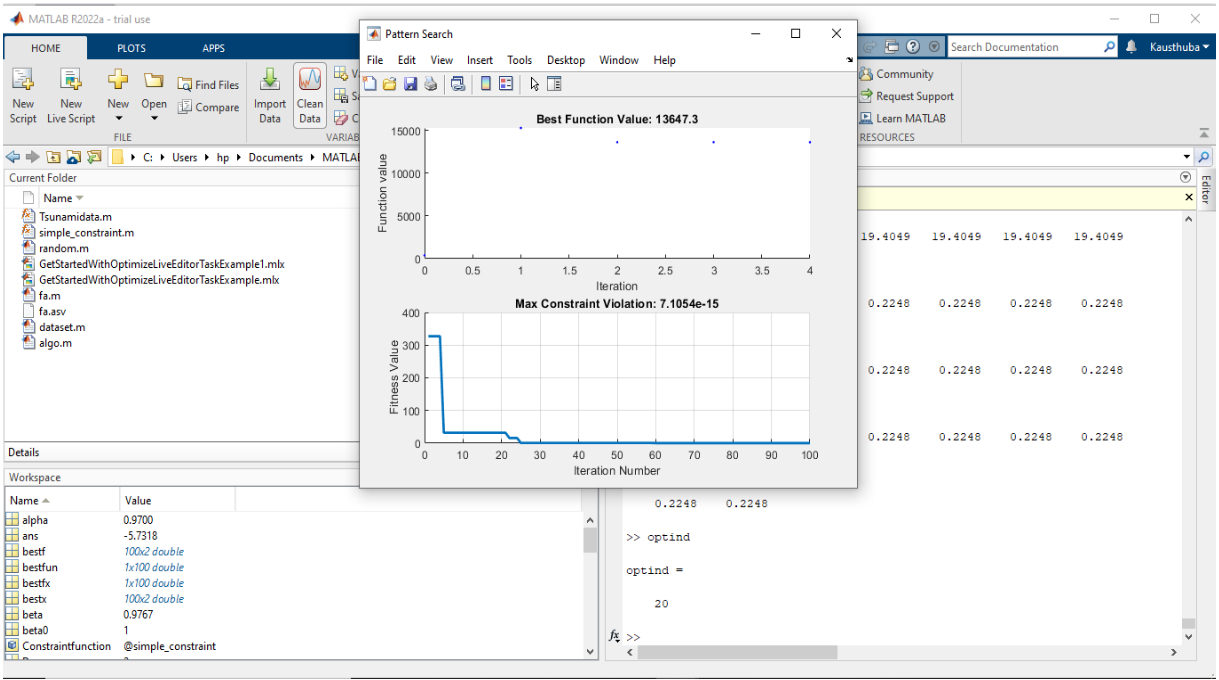
Optimum solution is obtained at the 50 iterations, which is inside the iteration limit. FA-PS model give a balanced relationship with better exploration and exploitation. The model is faster and accurate which gives optimal location at which the sensor needs to be placed in-order to analyze the tsunami waves. FA-PS is the one of the most robust method in obtaining the optimal location of sensor deployment to detect tsunami waves.

7. RESULTS:

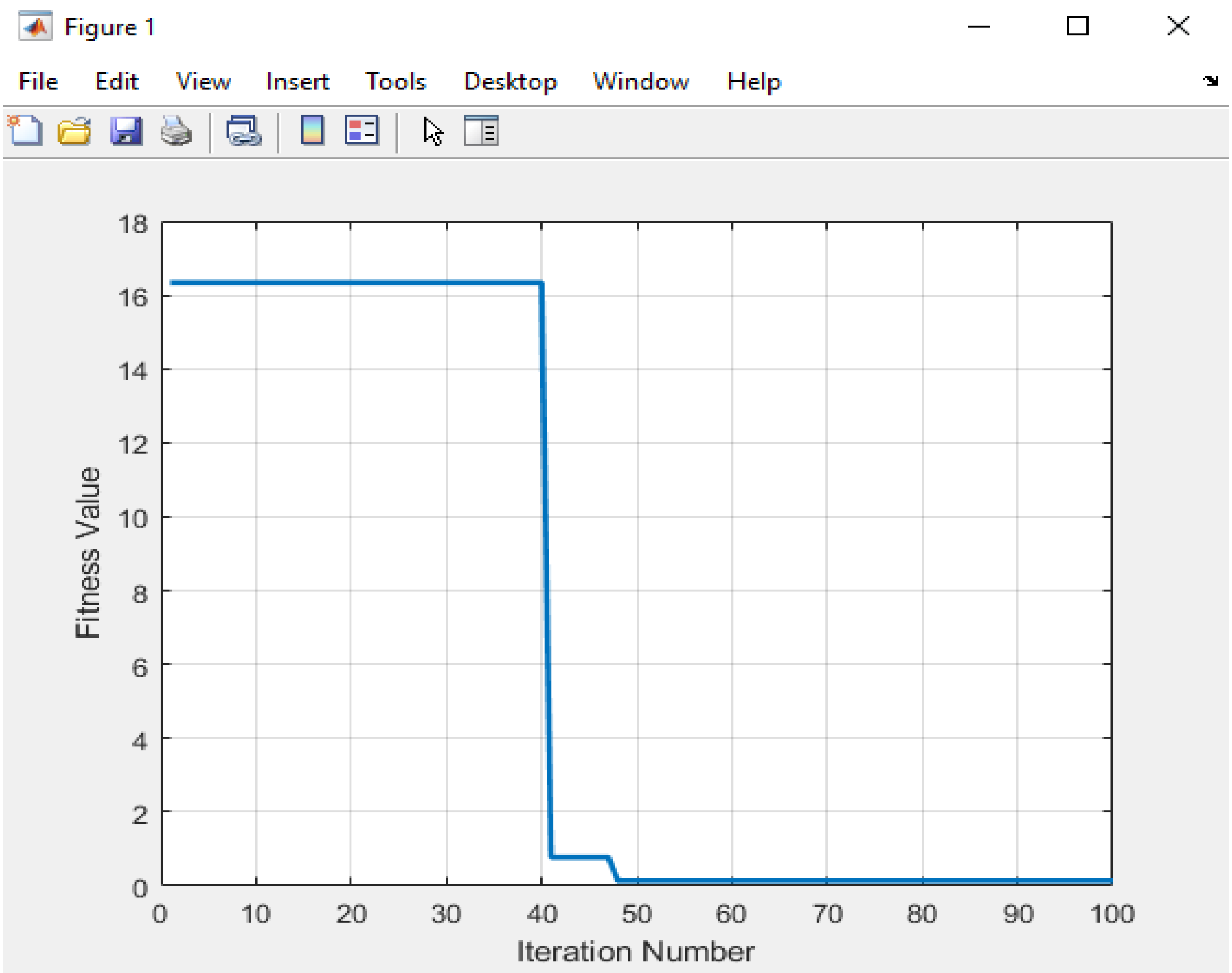
➢ Plot for Conventional FA algorithm:



➢ Plot for Pattern search algorithm:



➢ Plot for FA-PS Method:



➢ Code Snippet:

Objective function:

```
function y = objective(X)
x1=X(:,1);
x2=X(:,2);
 y = 100.*(x2-x1.^2).^2+(x1-1).^2;
end


D=2;
lb=[-5 -5];
ub=[5 5];
N=20;
```

```
alpha=1.0;
beta0=1.0;
gamma=0.01;
theta=0.97;
iter_max=100;

objfcn = @objective;

for i=1:N
for j=1:D
pop(i,j)=lb(:,j)+rand.*(ub(:,j)-lb(:,j));
end
end

fun=objfcn(pop);
alpha = alpha*theta;
scale=abs(ub-lb);

for iter=1:iter_max
for i=1:N
for j=1:N
fun(i)=objfcn(pop(i,:));
 if fun(i)<fun(j)
 pop(i,:)=pop(i,:);
 elseif fun(i)>fun(j)
 Xi = pop(i,:);
 Xj = pop(j,:);
 r=sqrt(sum(Xj-Xi).^2);
 beta=beta0*exp(-gamma*r.^2);
 steps=alpha.*(rand(1,D)-0.5).*scale;
 Xnew=Xi+beta*(Xj-Xi)+steps;
 end
 end
 end
for k=1:size(Xnew,2)
 if Xnew(k)>ub(k)
 Xnew(k)=ub(k);
elseif Xnew(k)<lb(k)
 Xnew(k)=lb(k);
 end
end
fnew=objfcn(Xnew);
if fnew<fx(i)
```

```
 fun(i)=fnew;
 pop(i,:)=Xnew;
end
```

Pattern search:

```
x0 = [1,3];
lb=[0 0];
ub=[1 13];
//Simple Constraint//
@ function [c, ceq] = simple_constraint(x)

c = [1.5 + x(1)*x(2) + x(1) - x(2);
     -x(1)*x(2) + 10];

% No nonlinear equality constraints:
ceq = [];

Constraintfunction=@simple_constraint;

options =
optimoptions(@patternsearch,'PlotFcn',{@psplotbestf,@psplotmaxconst
r}, ...
                                       'Display','iter');
[x,fval]= patternsearch(objfcn,x0,[],[],[],[],lb,ub,
Constraintfunction,options);


[Optval,optind]=min(fun);
bestfun(iter)=Optval;
bestf(iter,:)=pop(optind,:);
disp(['Iteration and Best cost is : (', num2str(iter), ',',
num2str(bestfun(iter)), ')']);

 plot(bestfun,'linewidth',2);
 xlabel('Iteration Number');
 ylabel("Fitness Value");
 grid on
end
```

8. References:

[1] Strumberger, N. Bacanin and M. Tuba, "Enhanced firefly algorithm for constrained numerical optimization," *2017 IEEE Congress on Evolutionary Computation (CEC)*, 2017.

[2] https://oceanservice.noaa.gov/facts/tsunami.html