Shape Optimization of Swarm Robot

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ABSTRACT

Shape Optimization attempts to integrate the geometrical modelling, Structural analysis and optimization into one complete and automated computer aided design process. It determines the optimal shape of the object while considering all of the conditions. This paper presents are simpler and less computationally expensive technique to perform the Shape optimization. Finite elemental analysis on limited number of model and generation of Surrogate model is the key idea to limit the number of simulations. Finally, The Genetic Algorithm is implemented to obtain the optimal shape of the model. This complete procedure is implemented for the Swarm robot, where it's optimal shape is obtained while considering all of the conditions and constrains.

Keywords: Optimization, Surrogate, ABAQUS, MATLAB

I. INTRODUCTION

Shape optimization is one of the techniques where the optimal shape is identified satisfying it's all constrains. In this paper, a technique is represented where by using the concept of shape optimization an optimal shape of a model is identified which satisfies all the requirements. Optimization of volume of a model comes under the structural optimization. In this optimization technique low stressed material is progressively eliminated. Structural optimization is a broad category where the geometry as well as topology of the object is optimized. Structural optimization is further classified into two categories Shape optimization and Topology Optimization. However, obtaining the optimized model is most challenging task in structural design domain.

Various approaches are there to solve various problems of structural optimization, one of the approaches depend on the development of the iterative technique, which uses at each iteration the information gained at several design points in order to fit better constrain and objective function. Another approach where the Structural optimization is done using the particle swarm approach, in this the implementation of PSO algorithm to solve structural optimization had shown with the effect of setting different setting parameters. Another paper where a genetic programming-based approach is presented for simultaneous sizing, geometry, and topology optimization of structures. In this an encoding strategy is presented to map between the real structures and the genetic programming parse trees.

Furthermore, Topology optimization which is considered as one of the difficult domains in optimization, which comes under the domain of Structural optimization. Topology Optimization optimizes material layout within a given design space, for a given set of loads, boundary conditions and constraints with the goal of maximizing the performance of the system. Many researches have been done on the topology optimization. This paper topology optimization approaches, deals with the complete overview, comparison and critical review of the different approaches, their strengths, weaknesses, similarities and dissimilarities about the various methods such as topological derivative, phase field, density, level set and evolutionary methods. Moreover, from this paper we can conclude that topology optimization is implemented only using a gradient-based optimization technique. On the other hand, through the heuristic approach which is based on randomness, isdifficult for topology optimization.

Shape optimization can be carried out through various techniques and these techniques are distinguish on the basis of finite elemental analysis which will done before, between or at the end of optimization. Various methods have various issues and benefits. As to process Analysis in every iteration of optimization will cause heavy computational work but results into accurate optimal shape on the other hand to perform analysis on lesser model before the optimization algorithm will results in lesser computational work but need to compromise with the accuracy.

In this project finite elemental analysis has done on selected models and obtain the approximate model named as surrogate model and then perform optimization on this obtained function of surrogate model. Surrogate modeling aims to provide a simpler, and hence faster, model which gives the specified output of a more complex model in function of its inputs and parameters. Surrogate modeling is generally applicable for the simulation of complex shape or in computational fluid dynamics. Surrogate modeling basically covers almost all of the design space region to obtain functional value at every region. And generate an approximating model from these selected points.

Many popular model to obtain the approximating functions are Polynomial response surface, Kriging, Gradient Enhanced Kriging, Radial Basis function, support vector machines, space mapping and artificial neural networking. After obtaining the approximating model function, the optimization has done to obtain the optimum shape values. Genetic algorithm which is famous for the more exploratively and expletively than other algorithms. Genetic Algorithm is a heuristic technique inspired by the natural selection that belongs the bigger class of evolutionary algorithms. In this a random population is generated and through generation (iteration) evolves to the optimum value. There are various algorithms to perform optimization but due to more accurate results this algorithm is preferred over other algorithms. Most of the work related to the Shape Optimization is on performing the simulation in optimization itself, which results into high computational work. But this work obtains the optimal shape with less computational expenses. According to the required model's condition are basic model is created and accordingly the final optimal shape is obtained. This displays the convenience regarding the usage of this technique. This approach develops the robust model, satisfying all of its requirements. While just developing the basic model and the loading conditions, the suitable model for the instances is obtained.

II. PROJECT LAYOUT

In Problem formulation complete shape optimization process has mentioned. In this form the basic model selection till the final geometry (optimized shape) the outline is given and detailed explanation is given in further methodology section.
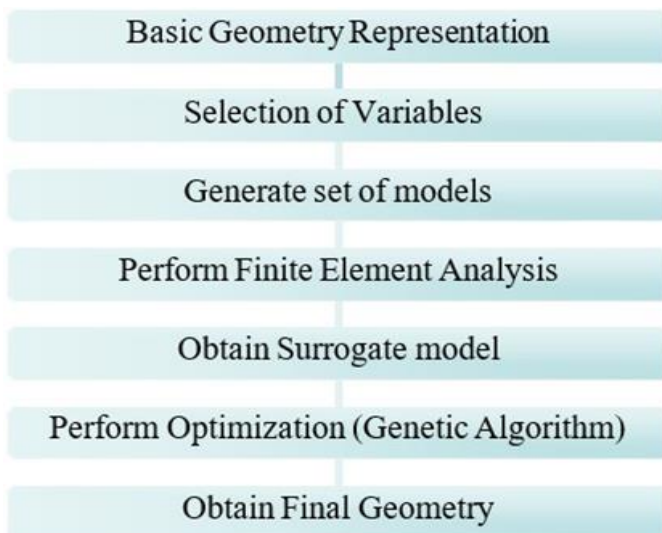
Basic Geometry Representation

Selection of Variables

Generate set of models

Perform Finite Element Analysis

Obtain Surrogate model

Perform Optimization (Genetic Algorithm)

Obtain Final Geometry

Figure 1: Outline of shape optimization

III. METHODOLOGY

In this section all the process for the Shape Optimization is elaborated in detail. In my work Swarm Robot example is considered. Where its optimum shape is obtained while satisfying it's all requirements. The total size of the final Swarm Robot model is comparatively smaller and difficult to obtain the optimum shape of the model without optimization technique, thus the Shape optimization technique helps to achieve exact optimum model considering all of its conditions.

The complete procedure is explained below with the final results with Swarm robot model.

1. Geometry Representation

The first step in the optimization process is to select a basic geometry according to our requirements. In one of the earliest works on shape optimization [16], where the finite element method was used to analyze the designs, and the finite element mesh was used as the geometrical representation. The coordinates of the boundary nodes were used as design variables. However, this idea was facing difficulties to maintain a smooth boundary shape using this representation. From the above we can conclude that the design model has to be separated from the analysis model because boundary smoothness is a basic requirement

when choosing a geometrical representation for shape optimization and geometrical representation with the finite element analysis creates geometrical imperfection which results into failure of model.

Thus, in my work first basic geometry is created according to the requirements and loading conditions. The preferred basic model is shown in the figure 2. The basic modelling of the model is done according to the space required to adjust all the components and its use. Thus, in this model two layers (upper and lower layer) is considered with the support of four column. The Space between the column and the complete inside space is decided according to the size of the equipment's that need to install. This finally after shape optimization we obtain with the optimal design which will satisfies all the requirements.
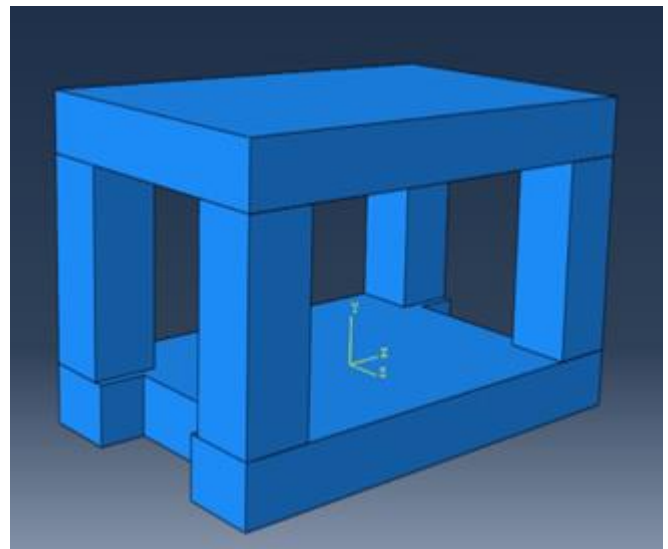

Figure 2: First geometry design

Material selection –
- ABS Plastic – Butadiene, styrene DH
- Young's Modulus – 380000psi = 2620.0078 MPa
- Poisson ratio=0.35

For loading –
- A constant load of 750 gm of weight are applied on two surfaces as shown in figure 3. (This weight is considered as the weight of battery and equipment's).
- Approximately 4745 Pa of load is considered on each surface as the load applied due to loading and unloading conditions while removing and attaching the equipment's.

Boundary Conditions –

- For analysis purpose the boundary condition is applied at the bottom surface where all of the nodes of lower most surface is fixed.
- For the bottom surface to be fixed, in the ABAQUS software, the boundary conditions are assigned to ENCASTRE which means that all the linear and rotational displacements are restricted.
- Symbolically, it is represented as U1 = U2 = U3 = UR1 = UR2 = UR3 = 0

The complete loading and boundary conditions is shown in the below figure.
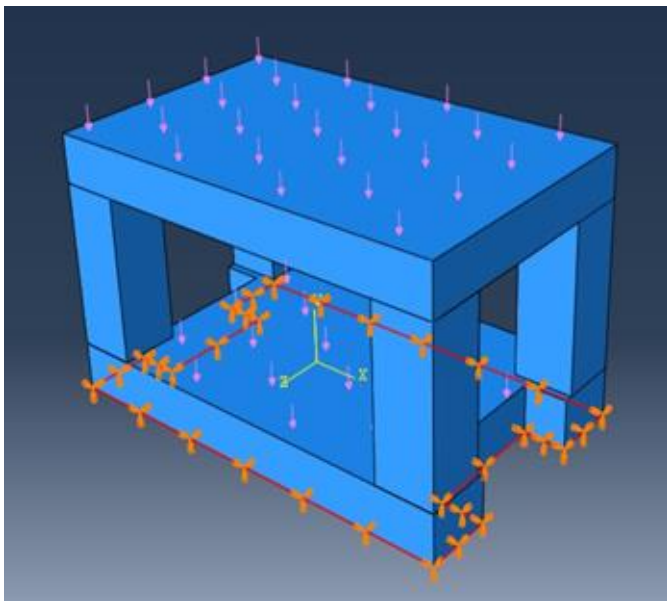

Figure 3: Geometry considering loading and boundary conditions

In my work complete geometry generation and all the finite elemental analysis procedure is being done in ABAQUS environment. To obtain the procedure code that ABAQUS is implemented at the back for complete geometry generation and analysis, macro recording function is used. Where complete code is generated in the python script. Which will be useful for further generation of models.

2. Selection of Variables

In this shape optimization, we considered dimensions of a model as a design variable. The design variables are selected on the basis of geometrical complexity and computational requirements. More number of variables can be selected for small or less complex geometry. In my case for the Swarm Robot, we have considered four variables. Which are the length and breadth of a column and thickness of the upper and lower surfaces.

3. Generate Set of Models

As to obtain approximate surrogate model, the results from few numbers of selected models' output has considered. Surrogate model is an approximation model, which is generated through selected number of models eventually reduces the amount of analysis. Furthermore, the number of generated models is decided on the basis of accuracy requirement computational effort. In my case for the analysis, we selected 20 different number of models. Selection of number of models also depends on number of variables. These variable values are taken in a method of design of experiments using the Latin hypercube sampling. Latin hypercube sampling (LHS) is a statistical method for generating a random sample of parameter values from a multidimensional distribution. This randomly generated values are substituted into the ABAQUS python script and obtain differentmodels with generated variables.

For the meshing the size of the seed part is selected as 2.5 and deviation factor and size factor as 0.1 and 0.1 respectively.

The MATLAB code used for the generation of sampling points is shown in the figure below.

```
1    % Upper and lower limits
2    XL1 = 2; XU1 = 8;
3    XL2 = 2; XU2 = 8;
4    XL3 = 2; XU3 = 8;
5    XL4 = 2; XU4 = 8;
6
7    S = lhsdesign(20,4);
8
9    % Generated points in required limits
10   x1 = (XL1 + (XU1-XL1).*S(:,1));
11   x2 = (XL2 + (XU2-XL2).*S(:,2));
12   x3 = (XL3 + (XU3-XL3).*S(:,3));
13   x4 = (XL4 + (XU4-XL4).*S(:,4));
14     Y = round(horzcat(x1,x2,x3,x4))
```

Figure 4: MATLAB code for generating random sampling points.

4. Perform Analysis

Obtained script for different models then run into the ABAQUS through command line and generate final output for all models. The complete geometry generation, loading, material selection and meshing is done in the ABAQUS and gives an output in (.inp format). The input file contains all the information regarding model geometry, material property and selected methods for analysis.

Abaqus2matlab tool which is available in MATLAB is further used to perform the analysis and obtain the final required results. In this the generated input files from the ABAQUS are processed. Abaqus2Matalb is a toolbox which connects the ABAQUS and MATLAB software conveniently. It helps to complete all the analysis from the ABAQUS output files. It stores all the required output values after analysis. This toolbox is widely useful when more than one analysis is performed or requires different output values for further analysis purpose. Furthermore, this toolbox generates all the required output values, in case we generated normal strain values and stored in excel format. In our project we have used the maximum displacement in the Y- direction in order to make the corresponding surrogate model more sensibly. We have taken maximum nodal displacement values in Y direction to ensure that, that is the maximum displacement a node can have in the model.

Below figure shows the displacement values generated from ABAQUS2MATLAB toolbox.

	1
1	5.0261e-...
2	1.0744
3	9.7263e-...
4	5.4303
5	0.2743
6	2.1773e-...
7	3.4522
8	0.1758
9	9.7562e-...
10	0.0092
11	0.0559
12	5.0260e-...
13	6.3093e-...
14	0.2162
15	6.2734e-...
16	8.8470e-...
17	0.0020
18	0.0205
19	7.0093e-...
20	0.0080

Figure 5: Nodal displacement of 20 models

And similarly, the volume of each model is calculated and the figure shows the volume obtained.

	1
1	21856
2	16816
3	11188
4	16232
5	16400
6	23060
7	19476
8	17356
9	14224
10	12216
11	19032
12	9652
13	18220
14	11832
15	21320
16	6820
17	18276
18	16344
19	15756
20	15032

Figure 6: Volume of 20 models

5. Generate a Surrogate model

Obtained strain values from the analysis have used to generate approximate surrogate model. In my work surrogate modelling method is used as it is very computationally expensive to perform finite elemental analysis on every model in every iteration, i.e., to perform nearly thousands of simulations for single shape optimization problem which will lead to days of computational work. On the other hand, this Surrogate modelling method generates an approximating model which will eventually processed for optimization to obtain optimum variable values.

In my work from the 20 sets of models two approximating model (Surrogate model) is generated, which gives approximating function values and helps to solve in the optimization algorithm. First approximating model is generated form normal strain values which is used as a constrain function in optimization. Another approximating model is generated from the volume of all the models.

Surrogate model is generated with the help of polyfitn function and polyn2ysm in MATLAB software. Basically, polyn2sym builds a function of multi dimension. In our work, we have generated two 5 dimensional functions. That is, first one on the basis of volume and the second one on the basis of nodal displacement. Now using the multi-dimensional function of nodal displacement as a

constraint, we have found the optimized values of 4 variables for which the volume is found to be the minimum. In further step, the optimization is performed.

6. Perform Optimization

Optimization is broadly classified into two types, Gradient based optimization and Heuristic optimization. Heuristic techniques are used in my work. Various techniques form Heuristic Optimization such as Genetic Algorithm, Particle Swarm Optimization, Ant colony optimization, Predator pray algorithm etc. Different techniques have different advantages and issues. Thus according to my model requirements, genetic Algorithm technique is selected.

The genetic algorithm (GA) is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution. Genetic algorithm repeatedly modifies the population of individual solutions through the iteration (Generation called in Genetic algorithm terms). It is basically evolving towards optimal solution. It involves some operations such as Crossover and Mutation which indirectly maintains the exploration and exploitation phenomenon. Genetic algorithm converges slowly compared with the Particle Swarm Optimization but preserves good properties of exploration and exploitation in searching process. Thus, in my case only one performance of optimization algorithm is required, thus there are no such requirements of fast convergence. Moreover, Genetic algorithm give more robust results, thus Genetic Algorithm is preferred over other Heuristic algorithm.

To perform the optimization the variables are, length and breadth of column, thickness of upper and lower part. Furthermore, the objective function is to obtain the minimum volume considering all conditions and constrains. Constrains are the upper and lower bounds of the variable and maximum normal strain value.

Optimization Problem –

Objective function:

Minimize F = Volume.

Subjected to:

Normal strain ≤ 1;

$2 \le Lc \le 8$;

$2 \le Bc \le 8$;

$2 \le Tl \le 8$;

$2 \le Tu \le 8$;

Where, Lc – length of the column,

Bc – Breadth of the column,

Tl – Thickness of the lower part,

Tu – Thickness of the upper part.

To execute the above optimization problem, we have written a MATLAB code in order to get the best possible results. Various functions like "polyfit", "polyn2sym", "ga" are used to construct this MATLAB code. This code will give us the optimum values of 4 variables and along with that, it will give us the best function counts in different iterations and the maximum constraints.

The code is shown in the figure below.


```
disp('GA optimization is running')
load disp_vol.mat
S = readmatrix('Training_points.txt');
S1 = S(:,1);
S2 = S(:,2);
S3 = S(:,3);
S4 = S(:,4);
%Fit Objective Function
Fit_Vol = polyfitn([S1,S2,S3,S4],volume,2);
Fit = polyn2sym(Fit_Vol)
% Fit Constraint
Fit_Disp = polyfitn([S1,S2,S3,S4],displacement,2);
Fit = polyn2sym(Fit_Disp)
X = [3,5,8,5]
Vol_Eq = Obj_fcn(X)
Strain_Eq = simple_constraint(X)
%%
%ObjectiveFunction = @A;
nvars = 4;    % Number of variables
LB = [2 2 2 2];   % Lower bound
UB = [8 8 8 8];   % Upper bound
%Constraint= rbf_trainer(S,displacement);
% displacement
ObjectiveFunction = @Obj_fcn;
Constraint = @simple_constraint;
options = optimoptions(@ga,'MutationFcn',@mutationadaptfeasible);
options = optimoptions(options,'PlotFcn',{@gaplotbestf,@gaplotmaxconstr}
   'Display','iter');
 [x,fval] = ga(ObjectiveFunction,nvars,[],[],[],[],...
   LB,UB,Constraint,options)
```

Figure 7: MATLAB code for surrogate model and optimization

7. Obtain Final Geometry

The Obtained variables values through the optimization are substituted into the generated python script from macro recording. The final model with the complete simulation is obtained which satisfies all the conditions and constrains. The final model is mentioned in the further section of Results and discussion.

IV. RESULTS AND DISCUSSION

The shape optimization has been done on the selected geometry of swarm robot. Surrogate model is generated using available MATLAB package PEMF and thereafter the optimization is being done using MATLAB ga command. The complete shape optimization required codes is attached with this report. The results and final optimized geometry after shape optimization is shown below. The final obtained variable values (Lc, Bc, Tl, Tu) after optimization are (2.0001, 2.0000, 5.6208, 20077). Furthermore, the obtained best function value is 6803.62. The best function value is shown with the number of generations in below figure. As the design variable space and number of variables are fewer thus complete optimization is done in five generations and algorithm is terminated in four iterations.

Generation	Func-count	Best f(x)
1	2524	6674.59
2	4992	6573.26
3	7977	6589.23
4	15221	6567.48

Figure 8: Best function value with the generation.

Further, the plot of best function value i.e. the minimum volume and the maximum nodal displacement is shown in the below figure.
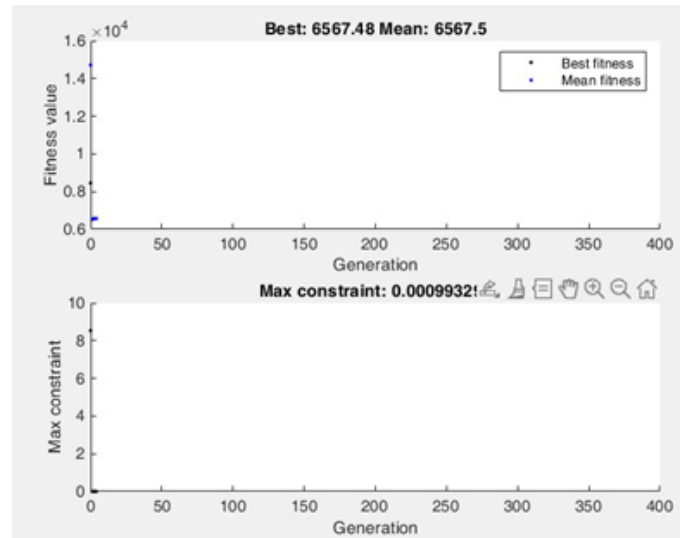

Figure 9: Plot of volume and constraint functions

Obtain optimized values are substituted into macro recorded python script and the final geometry is generated, as shown below in figure 10.
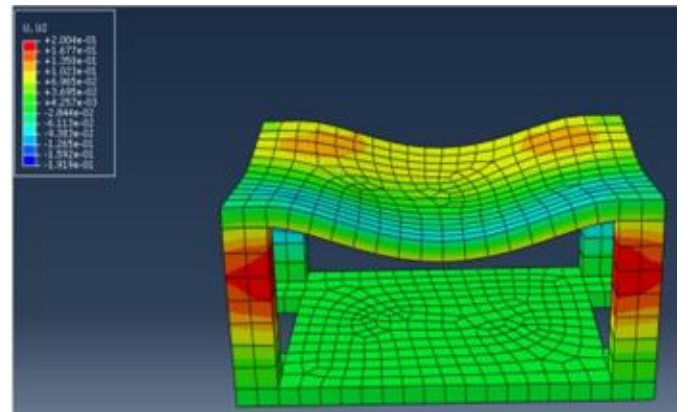

Figure 10: Final geometry

Furthermore, many of the complex geometries is possible to optimize with this technique. This report gives the complete understanding of technique for shape optimizations with the simpler model, a smaller number of variables and constrains.

V. CONCLUSION AND FUTURE SCOPE

Structural Optimization is considered as one of the difficult optimization tasks, but this method introduces an approach to perform the shape optimization in simpler and less computationally expensive manner. The technique is developed where surrogate model is created and optimal shape is

obtained in least number of simulations. The validity of this technique is examined by solving the Swarm Robot model and obtain the optimal shape of the model.

There is wide scope to utilize the heuristic algorithm in Topology Optimization. Currently for all the Topology Optimization has done using Gradient based method as there is difficulties to perform the Topology optimization with population-based algorithm which is based on some randomness phenomenon. Furthermore, the selection of material from different materials can also be possible which eventually leads to the optimum shape with the optimum material with required conditions and constrains.

Furthermore the process of creating the input files and creating the python scripts of newly obtained models from Latin hypercube sampling method can be automated using codes in python languages.

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