Chapter 1

INTRODUCTION

1.1 TRENDS IN OPTIMIZATION

In today's world of cut-throat competition and increased consumer demands, solutions often require to be optimum and not just feasible. Minimization of cost and maximization of profit is the major objective of any industry nowadays. With enormous high speed computing power at his disposal, men's striving towards excellence has received a major breakthrough. This has made "optimization" the buzzword of recent times. Optimization in a broad sense is minimization or maximization of an objective function subject to certain conditions or constraints. In structural engineering design problems weight or cost of the structure is considered to be the objective function subject to stress, displacement constraints and variable bounds.

Most of the optimization algorithms [1-3] are based on numerical linear and nonlinear programming methods that require substantial gradient information and usually seek to improve the solution in the neighborhood of a starting point. These hard computing algorithms, however, reveal a limited approach to complicated real-world optimization problems because, (i) the optimum result may depend on the selection of an initial point and, (ii) they are deficient in dealing with imprecise and uncertain information which human being use in day to day routine. Moreover hard Computing requires precise algorithms that generate the exact solution.

Soft computing [4-6], on the other hand, could be seen as a series of techniques and methods so that real practical situations could be dealt with in the same way as humans deal with them, i.e. on the basis of intelligence, common sense, consideration of analogies, approaches, etc. In this sense, soft computing is a family of problem-resolution methods headed by approximate reasoning and functional and optimization approximation methods, including search methods. Soft-Computing (SC) is a collection of techniques spanning many fields that fall under various categories in Artificial Intelligence (AI). The principal constituents of Soft Computing are Genetic Algorithms (GA), Fuzzy Logic (FL) and Artificial Neural Networks (ANN). Soft-computing, as opposed to "hard computing", is rarely prescriptive in its solution to a problem. Soft-computing, to some extent, draws inspiration from natural phenomena.

Genetic Algorithms [7] are founded on the dynamics of Darwinian evolution, Neural Networks [8, 9] try to mimic the human brain, while Fuzzy Logic [9-11] is heavily motivated by the highly imprecise nature of human speech. Also, a combination of one or more of these methodologies termed as hybrid systems [12, 13] has resulted in the emergence of a new class of systems such as Neuro - Fuzzy, Fuzzy – Genetic and Neuro - Genetic systems. Their healthy integration can produce solutions to problems that are too complex or inherently noisy to tackle with conventional mathematical methods.

Structural optimization [14] is the process of finding optimum shape and size of the structure while satisfying various constraints imposed by design codes and other functional requirements proposed by engineers and designers. Since the process involves multi design variables a robust optimization technique is required. Further, structural design process involves to some extent, imprecision and uncertainty due to human error and uncertainty involved in design methods and material behavior. It is stated by the researchers that classical methods do not perform well in such cases. On the other hand, many researchers have successfully used soft computing tools particularly GA for some such problems.

In the present work, therefore, the development of the software for optimum design of various structural components using the soft computing techniques such as GA, FL and ANN has been undertaken. Fusion of some of these techniques has also been attempted to explore probable improvement in their performance.

1.2 BASIC SOFT COMPUTING TOOLS

1.2.1 Genetic Algorithms

Genetic Algorithms (GAs) are adaptive heuristic search algorithms based on the evolutionary ideas of natural selection and genetics pioneered by Darwin in 1859. The basic concepts of GA were developed by Holland [15] in 1973. Since then various forms of GA have been developed and used for the optimization of complex systems [16]. GAs work on the population of pseudo-randomly generated solution strings known as chromosomes which are generally strings of bits, each of which is judged on their adaptation to the problem being addressed using a 'fitness function'. The fitness function evaluates the solution and returns a numerical answer, which rates the solution's suitability. This population is then transformed in to new population by employing the operators inspired by the natural genetic operators. Only the fit chromosomes survive and are allowed to reproduce offsprings. Among those surviving chromosomes, the fitter chromosome reproduces more offsprings than the less fit ones. The three main genetic operators are the crossover, the mutation, and the inversion operators. The other operators used by the researchers are elitism, niche, cloning etc. When the generation of a new population is completed, stopping criteria are evaluated. If the stopping criteria are met, the algorithm stops. Otherwise, the fitness function is used again to obtain the fitness degree of the new population.

The areas of application of GAs, and their variations, have been diverse. The most successful applications are in the areas of optimization, automatic programming, machine learning, economics, immune systems, ecology, population genetics, evolution and learning.

1.2.2 Artificial Neural Networks

The origin of Artificial Neural Networks (ANNs) goes back to 1943 when Rosenblatt developed a single layer perceptron to generate a linear decision function for pattern recognition. Since then, a large variety of NNs have been developed with the purpose of solving different classes of problems [4]. According to Lippmann, ANNs can be classified depending on the input i.e. binary or continuous valued. They are further classified based on the learning modes, i.e. unsupervised or supervised. While feed forward NNs are commonly used for supervised learning problems, the feedback NNs are helpful for unsupervised learning. One of the most widely used feed forward networks is Backpropagation Neural Network (BPNN). It can learn relationship between input and output, solely by selection of numerical weights, NN topology and learning rate. There may be any number of hidden layers, and any number of hidden units in any given hidden layer. In feed forward activation, units of the first hidden layer compute their activation and output values and pass these on to the next layer, and so on until the output units will have produced the network's actual response to the current input presented to the input layer.

Neural networks have been applied to a wide variety of different areas including speech synthesis, pattern recognition, diagnostic problems, medical illnesses, robotic control and computer vision. Many researchers of structural engineering have also applied ANN successfully for solving structural engineering problems in input-output simulation. However, its reported applications in optimization field are rare.

1.2.3 Fuzzy Logic

Fuzzy Logic (FL) is built on The *Fuzzy Set Theory*, which was introduced to the world, for the first time, by Lotfi Zadeh in 1965. The invention, or proposition, of Fuzzy Sets was motivated by the need to capture and represent the real world with its fuzzy data due to uncertainty. If intelligent systems are to mimic human beings, these should also be able to handle the same imprecision and uncertainty of human thought processes. In classical set theory, an object could just be either a member of set or not at all whereas in fuzzy set theory, a given object is said to possess certain "degree of membership" to the set. This degree of membership is calculated using a membership function [11].

Fuzzy inference systems have been used successfully in various fields such as pattern classification, fuzzy clustering, modeling, process control, signal processing, image processing and natural language processing etc. FL can be used for optimization of structures using max-min procedure. However, its reported applications in literature are very few.

1.3 HYBRID SOFT COMPUTING SYSTEMS

The real world often has problems that cannot be solved successfully by a single basic technique, each technique has its pros and cons. The concept of hybrid system in AI consists of combining two approaches, in a way that their weaknesses are compensated and their strengths are boosted. A number of hybrid system possibilities are described below in brief.

1.3.1 Integration of GA and FL

A GA – Fuzzy hybrid system is basically a fuzzy system augmented by a robust search capability of a genetic algorithm and thereby offers a valid approach to problems requiring efficient and effective search processes. Fuzzy Logic can be implemented to fuzzify various GA parameters and constraint functions to incorporate the imprecision and uncertainty and to improve the search capability of GA towards global optimum solution. In traditional optimization algorithm the constraints are satisfied strictly due to which it can miss true optimum solution within the confine of practical and realistic approximation. In real life design problems, design methods and constraint evaluation involves fuzziness and imprecision. Also during the design state, the decision making in the shape design of structures is mainly based on the conceptual understanding. Unfortunately such information is usually vaguely defined by the experts. Therefore, consideration of imprecise and vague information becomes an important aspect in the structural optimization. Moreover, if some candidate solutions are thrown out because they violate one or more constraints during the early optimization process, then the search may miss the potentially global optimum solution. In other words, by treating the constraints as fuzzy constraints the chance of obtaining global optimum can be increased.

1.3.2 Integration of NN and GA

Neural networks and genetic algorithms demonstrate powerful problem solving ability. They are based on quite simple principles, but take advantage of their mathematical nature: non-linear iteration. The inspiration of the idea of combining them comes from nature. In real life, success of an individual is not only determined by his knowledge and skills, which he gained through, experience (neural network training), it also depends on the genetic heritage (set by the genetic algorithm). Thus, by combining both jewels of AI, their performance can be enhanced. A GA may be run first to get right hill and NN may be used to climb the hill to reach its peak. The performance of a NN for a particular problem is critically dependant on, among others, the choice of the processing elements (neurons), the net architecture and the learning algorithm and connection weights. Selection of these network parameters is very crucial and time consuming. The power of GA can be used to discover suitable domain specific network parameters to accelerate the learning process of network.

1.3.3 Integration of NN and FL

The performance of Artificial Neural Networks becomes degraded and less robust when the inputs are not well defined, i.e., fuzzy inputs. Neurons in ANNs also do not function properly when network parameters are fuzzy. On the other hand, fuzzy systems are not capable of learning. Moreover, the fuzzy rules that define the input/output relationship must be known in advance and usually need to be written and tuned by hand. When expert knowledge can be used to write these systems then this task is relatively simple, but this is not always possible to find experts in the problem domain. Therefore, combining the two technologies to create hybrid systems that fill the gaps of one paradigm by means of the other is highly desirable.

1.3.4 Integration of GA, NN and FL

Genetic fuzzy neural networks are the result of adding evolutionary learning capabilities to systems integrating fuzzy and neural concepts. The usual approach is that of adding evolutionary learning capabilities to a fuzzy neural network that usually is a feed-forward multilayered network to which, previously, some fuzzy concepts were incorporated. The result is a feed-forward multilayered network having fuzzy and genetic characteristics. Genetic fuzzy neural networks incorporate fuzzy numbers to represent the weights, perform fuzzy operations in the nodes of the network, and/or incorporate fuzzy nodes that represent membership functions. In addition, the learning process applies GAs to obtain the weights of the NN, to adapt the transfer functions of the nodes, and/or to adapt the topology of the net.

1.4 SCOPE AND OBJECTIVES OF THE PRESENT WORK

Review of literature revealed that GAs have been mainly used for the optimum design of steel structures. Optimization of RCC structures have been tried by very few researchers. Moreover, optimization of structures involving multi design variables using GAs is computationally intensive and has not received much attention. Also, it is clear from the available literature that there has been very few attempts of using Fuzzy Logic for optimization of structural components. The main objective of the present work is, therefore, to develop the software for the size optimization of various RCC and steel structural components and to attempt configuration and topology optimization of structures, where possible, using basic as well as hybrid soft computing techniques discussed in the preceding sections.

The aim is to find suitability of different soft computing techniques for optimization and to combine them for intensifying the capability of individual techniques. Various programming packages are developed in Visual Basic with pre- and post-processing capabilities for optimum design of RCC structures such as slabs, plane frames, grids, combined footings, retaining walls, silos, folded plates and machine foundations and steel structures such as steel portal frames, plane and space trusses and gantry girder. It is also aimed to increase the scope of this work by developing the programs for optimum design of concrete mix using Neuro-Fuzzy-GA approach and topology optimization of continuum structures using GA and GA-Fuzzy techniques.

Thus, the present work aims to explore application of different soft computing methodologies and to find their relative merits in the following structural optimization areas.

1. **Optimum Design of RCC Plane Frames**

   Optimum design of plane frame which is made of several beam and column elements is a multiple variables optimization problem for which GA and FL based programs are developed. Minimization of the cost of plane frame through size optimization of different structural elements is the main objective in this optimization problem.

2. **Optimum Design of Footings**

The structural design of an isolated footing is trial-and-error process for fixing the dimensions. Cost is considered as the objective function to be minimized. In addition to geometric constraints and stress constraints, soil pressure constraint is also imposed on the search process. Base dimensions and depth of the footing are considered as main design variables in GA based approach.

Optimum design of combined footings for given geometry restriction of planned dimensions, soil data and loads is attempted using fuzzy logic. The thickness of footing is considered as main input parameter and shear strength of concrete and actual shear stress due to given loading as induced and performance parameter respectively.

Also a hybrid GA – Fuzzy approach for cost optimization of combined footing subjected to various constraints involving imprecision and fuzziness is addressed. A hybrid approach employed here divides the fuzzy optimization problem in three non-fuzzy optimization problems. Each of these problems is then solved by pure GA.

3. **Optimal Design of Machine Foundations**

The design of machine foundation involves dynamic analysis of the machine foundation system. The dimensions of the machine foundation block should be so as not to violate the frequency and amplitude constraints. Dimensions of the foundation block are the design variables to be optimized to get minimum cost while satisfying all the static and dynamic constraints. Size optimization of block type machine foundation is attempted by developing GA and FL based softwares.

4. **Optimal Design of RCC Water Tanks**

An attempt has been made to arrive at such a combination of height, diameter, wall thickness and reinforcement that the overall cost of the tank is minimum for a given capacity. Objective function is the overall cost of the tank. The only constraint imposed in the optimization is the thickness of the tank as the water tanks are designed based on the theory of uncracked section. Example of flexible base water tank is included using the GA based optimization approach.

5. **Optimal Design of RCC Slabs**

   Various types of RCC slabs such as simply supported one-way, simply supported two-way, continuous one-way and continuous two-way slabs are undertaken for optimization via fuzzy logic. In all the cases depth of slab is considered as input parameter and actual and permissible span/depth ratios are taken as induced and performance parameters respectively.

6. **Optimum Design of RCC Grid Structures**

   A module is developed to carry out analysis, optimization and design of RCC grids with pre- and post- processing capabilities to facilitate the input and graphical output. Dimensions of the grid members are taken as input parameters and actual and permissible bending stress in concrete as induced and performance parameters respectively.

7. **Optimum Design of Gantry Girder**

   A gantry girder comprises of I and channel sections. There is no specific procedure available for the selection of the sections which turns it into trial-and-error process. Total weight of these two components is selected as objective function in GA based optimization. Main constraints are stress constraints and geometric constraints. Geometric constraints are imposed by selecting suitable lower and upper bound for the design variables.

8. **Size, Configuration and Topology Optimization of Plane Trusses**

   GA based methodology is used for obtaining optimum size and configuration of plane trusses. Optimization of size and configuration is carried out simultaneously. Size variables are considered as discrete and configuration variables as continuous. Weight of the truss is considered as objective function. GA search is subject to stress and displacement constraints. The aim is to try different selection schemes to find the best scheme. Two examples that are reported in the literature are solved for comparison purpose.

In topology optimization of trusses, the nodal coordinates, the member cross sectional areas, the member connectivity, the presence or absence of a node and presence or absence of member are treated as design variables. Weight of the truss is considered as an objective function to guide the search. In addition to usual stress, displacement and buckling constraints other constraints imposed are minimum length and maximum length of the member which are very much essential to remove very long and short members from the selected topology. The concept is demonstrated with the help of suitable example.

Also, for simultaneous size and configuration optimization of plane trusses, a genetic evolution based search technique with soft (fuzzy) constraints is explored for configuration optimization of trusses. This hybrid approach is used in minimum weight design of truss structures in which geometry of truss and member areas are considered as design variables to be optimized.

9. Topology Optimization of Space Trusses

This problem is described as one where a ground structure containing many points and members defines the discrete version of structural universe; and from which an optimal structure is derived. The present work includes an illustrative example of topology optimization of a cantilever space truss. A tetrahedron is considered as the basic unit of a space structure where connecting newly formed tetrahedrons to previously generated tetrahedrons generates the truss. The results obtained are compared with those available in literature to confirm the validity of the work.

10. Topology Optimization of Continuum Structures

A relatively complex problem of topology optimization of continuum structures like plates under plane stress condition is attempted basic based on Genetic Algorithm. A program is developed based on Finite Element Method (FEM) for analysis. The aim is to attempt the problem of plate using the proposed approach.

Further, topology optimization of two dimensional plate structures through the fusion of soft computing tools is also tried with the objective as minimizing the weight of the structure. To improve the performance of genetic algorithm, various behavioral constraints such as stress or displacement constraints are slightly relaxed using Fuzzy

Logic. A new constraint handling technique is proposed to guarantee single connected object in the final optimal topology. An identical bit array representation method is tried to assist this technique.

11. Optimization of Parameters of BPNN

BPNN can adapt themselves to different tasks, i.e. learn relationship between input and output, solely by selection of numerical weights, NN topology and learning rate. How to select these parameters, however, is a key issue in the use of neural networks. In this investigation, GA is utilized for selecting the neural network weights and topology so as to minimize the time required in training the BPNN. A Simulator is developed to take advantage of GA/BPNN mating and concept is demonstrated with the help of suitable example.

12. Optimization of Concrete Mix Proportions

The aim is to develop software based on combination of three soft computing tools i.e. GA, FL and NN to handle a complex problem of concrete mix design. As the use of fuzzy logic render the mix design process more natural, flexible and humanistic and as neural networks can be used to build up the relationship from the examples presented to them, mix design procedure is formulated by using Neuro-Fuzzy hybrid approach. Genetic algorithm is then used for optimization of concrete mix design. The multi-objective optimization concept is used for concrete mix. The mix design problem is converted into a mathematical programming problem in which the cost of concrete is minimized subjected to certain constraints like compressive strength, minimum cement content etc.

1.5 ORGANIZATION OF THE THESIS

Chapter 1 begins with trends in structural optimization. After emphasizing the need of soft computing tools, it describes basic soft computing tools and their hybridization possibilities followed by scope and objectives of the present work.

After discussing the various possibilities in optimization with the available methods to handle the same, various parameters related to optimization theory such as design variables, objective function, constraints etc. are discussed followed by description of the optimization problem formulation in **Chapter 2**.

As the main aim of the present work is to develop software based on various soft computing methodologies, the **Chapter 3** is devoted to review of work carried out by researchers in the field of structural optimization using Genetic Algorithms, Fuzzy Logic, Artficial Neural Networks and Hybrid soft computing techniques.

Chapter 4 gives an overview of Genetic Algorithm-a robust heuristic search optimization method, showing analogy between natural genetics and the optimization method based on natural genetics. After describing various elements of GA and chromosome selection schemes, steps of GA based optimization methodology are covered briefly.

Chapter 5 is devoted to the fundamentals of fuzzy set theory followed by introduction to various fuzzy systems including fuzzy logic based optimization procedure i.e. α-cut method. Fuzzification and defuzzification techniques are also discussed in detail in this chapter.

Starting with the general review of ANN, **Chapter 6** shows the comparison between biological and artificial neuron and defines neural network terminology. Finally the detailed description of feed forward back propagation neural network (BPNN) is included.

Chapter 7 starts with few words about complementary nature of various individual soft computing tools and thus introduces the hybrid techniques formed through the fusion of basic soft computing tools used in this research and found in the literature. It discusses the various possible combinations of GA, Fuzzy and ANN to enhance their basic capabilities.

After giving details of the selected environment and GA based software developed in the present work, various structural engineering optimization problems of RCC and steel structures solved by using GA are covered in **Chapter 8**. Various RCC applications included are optimum design of frames, retaining walls, isolated and combined footings, water tanks, silos, folded plates and machine foundation. The steel structures optimized ranges from one dimensional gantry girder to two dimensional plane frames/trusses and three dimensional space trusses. The software is developed to facilitate size, configuration and topology optimization of truss structures. Finally, the topology optimization of continuum structure is addressed.

Chapter 9 addresses the optimization problems solved by alpha-cut method of fuzzy logic. The RCC structures included in this chapter are various types of slabs, plane frame, grid structure, retaining wall, isolated and combined footing and machine foundation. Optimum design of complicated structures such as silos, folded plates, hyper shells etc. is also dealt with. Screen shots of menus and forms developed are given.

The ANN being a simulation tool, there are very few examples of use of ANN as an optimization tool since the design of ANN architecture for optimization problems proves to be computationally intensive and complicated. **Chapter 10** addresses the basic issues related to computer implementation of BPNN followed by one application of R.C.C. column.

The application of various hybrid soft computing techniques such as GA-Fuzzy approach, Neuro-GA approach, Neuro-Fuzzy approach and Fuzzy-GA-Neuro technique are covered in **Chapter 11**. The various problems solved include optimization of RCC combined footing, RCC column, plane truss, continuum plate structure and concrete-mix design.

Finally **Chapter 12**, after a brief summary, highlights the important conclusions and contribution of the present work and gives recommendations for future work.