ACOUSTIC SCATTERING REDUCTION IN ELASTIC MATERIALS
WITH BAT OPTIMIZATION ALGORITHM

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submitted by **ZEYAD ALGBURI** in partial fulfillment of the requirements for the degree of **Doctor of Philosophy** i**n Mechanical and Aeronautical Engineering, University of Turkish Aeronautical Association** by,

Assoc. Prof. Dr. Suat Dengiz
Dean, Graduate School of **Natural and Applied Sciences** _________________

Prof. Dr. İbrahim Halil Güzelbey
Head of the Department, **Mechanical and Aeronautical Eng.** _________________

Prof. Dr. Cihan Karataş
Supervisor, **Mechatronics Eng., THKU** _________________

Examining Committee Members:

Prof. Dr. Cihan Karataş
Mechatronics Eng.,THKU _________________

Assist. Prof. Dr. Mohammad Rafighi
Mechanical Eng.,THKU _________________

Assist. Prof. Dr. Javad Rahebi
Software Eng., Altinbaş University _________________

Assist. Prof. Dr. Abdellatif Baba
Mechatronics Eng., THKU _________________

Assist. Prof. Dr. Seçil Karatay
Electrical-Electronic Eng., Kastamonu University _________________

Date: 20.08.2020

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Zeyad Algburi:

Signature :

ABSTRACT

ACOUSTIC SCATTERING REDUCTION IN ELASTIC MATERIALS WITH BAT OPTIMIZATION ALGORITHM

Algburi, Zeyad
Doctor of Philosophy, Mechanical and Aeronautical Engineering
Supervisor : Prof. Dr. Cihan Karataş

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scattering-cancelation method is followed in this analysis. In addition, the opportunity to reduce the scattering effect in a rigid cylinder with elastic cloaking material is investigated. The rigid cylinder with elastic cloaking and without elastic cloaking is analyzed for regular plane waves to test the scattering effect of the rigid cylinder. The energy due to reflected and travelled waves is presented mathematically. The parameters of the elastic cloaking, such as thickness, density and Poisson ratio, are optimized using the Bat algorithm. Pressure filed of the rigid cylinder and directivity patterns scatter pressures in the cylinder are analyzed. The results revealed that Bat algorithm optimization provides better performance for elastic cloaking in the cylinder to reduce the scattering effect.

Keywords: Acoustic Scattering, Elastic Material, Bat Algorithm, Optimization

ÖZ

BAT OPTİMİZASYON ALGORİTMASI İLE ELASTİK MALZEMELERDE AKUSTİK DAĞITIMIN AZALTILMASI

Algburi, Zeyad
Doktora, Makine ve Uçak Mühendisliği Anabilim Dalı
Tez Yöneticisi: Prof. Dr. Cihan Karataş

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Bu çalışmada saçılma-iptal metodu kullanılmıştır. Ek olarak, elastik kaplama malzemesi ile sert silindirde saçılma etkisini azaltma fırsatı araştırılmıştır. Kaplamalı ve kaplamasız elastic malzemeli rigid silinderin saçılma etkisini test etmek için düzenli düzlem dalgaları analiz edilmiştir. Yansıyan ve hareket eden dalgalardan kaynaklanan enerji matematiksel olarak geliştirilmiştir. Kalınlık, yoğunluk ve Poisson oranı gibi elastik kaplamanın parametreleri, BAT algoritması kullanılarak optimize edilmiştir. Rijit silindirin basınç alanı ve silindirdeki yönelim paternleri saçılma basınçları analiz edilmiştir. Sonuç olarak, yarasa algoritması optimizasyonu saçılma etkisini azaltmak için silindirdeki elastik kaplamalar için daha iyi performans sergiledi.

Anahtar Kelimeler: Akustik Saçılma, Elastik Malzeme, Yarasa Algoritması, Optimizasyon.

I Dedicated This Thesis To My Parents

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LIST OF ABBREVIATIONS

ABBREVIATIONS

1D	:	One Dimensional
2D	:	Two Dimensional
3D	:	Three Dimensional
BC	:	Boundary Condition
ABC	:	Absorbing Boundary Condition
PDE	:	Partial differential Equation
Bi	:	Binary
SCS	:	Scattering Cross-Section
DOF	:	Degree of Freedom
FEM	:	Finite Element Method
SEM	:	Spectral Element Method
PSO	:	Particle Swarm Optimization

LIST OF SYMBOLS

SYMBOLS

h	:	Thickness
$\nu_{r\theta}$	:	Poisson's ratio
ρ	:	Mass density
c	:	Compressible sound level fluid
k	:	Wave number
$\bar{\phi}$	:	Dimensional velocity potential
$\bar{p}$	:	Aspect pressure
S	:	Separation constant
C,D	:	Arbitrary constant
A_n	:	Amplitude of wave
S_n	:	Amplitude of wavenumber
ϕ_n	:	Velocity potential
A_m	:	Amplitude of the scatter wave
B_m	:	Amplitude of the travelled wave
S_m	:	Wave number of the scatter wave
η_m	:	Wave number of travelled wave
a	:	Radius of the outer cylinder
b	:	Radius of the inner cylinder
c_s	:	Sound speed of the cloaking material

E	:	Young’s modulus
ρs	:	Density of the cloaking material
d	:	Number of optimizing parameter of the system
n	:	Number of Bat population
Q_i	:	Pulse frequency of the Bats
r_i	:	Pulse rate of the Bats
A_i	:	Loudness factor of the Bats
Q_{max}	:	Maximum frequency of the Bat
Q_{min}	:	Minimum frequency of the Bat
V(t)	:	Current iteration velocity
X^*	:	The best position
δ	:	Random number
$\emptyset$	:	Random number
W	:	Inertia weight
ξ	:	Smallest constant to avoid the probability of division
σ^2	:	Standard perversion

CHAPTER 1

INTRODUCTION

1.1 Background

Reducing acoustic scattering is important in modern society, as it has been proven to be detrimental to human and animal health. In general, there are many motivates to work and design systems to reduce the sources of noise pollution that comes from external surrounding such as systems of motor vehicle exhaust, vibrations of mechanical structural due to transfer the energy of acoustic waves through them. Many researchers in the past decades and modern have used silencers to dissipate the acoustic energy travelling from one medium to another. Also, in our daily life, we see that there are other sources of noise resulting from systems of ventilation, air conditioning and heating. Carrying the air from one place to another and guiding it should be pushed by a system of fans that produce unwanted noise. Moreover, there are external noise comes from outside will reach and spread within the waveguide. The cross-section of these waveguides, in general, is rectangular. Still, the designers, engineers and the workers in applied mathematics fields prefer the circularity or circular cylindrical shells, which has continued importance for studying the vibration and propagation of acoustic waves.

Various examples of the scattering of acoustic waves and sound radiation in media with solid (elastic) and fluid (acoustic) regions are found in daily life. The analysis of acoustic waves is a large field and used in many applications such as geological surveys, echolocation, nondestructive testing, radiolocation, and medical imaging.

The changes experienced by analysis of acoustic wave scattering over the past decade remain unprecedented, various methods were studied by many researchers using a barrier that was penetrable for sound waves. There are two essential methods currently being adopted in research into acoustic waves scattering.

The transformational acoustic wave method is the bedrock over which the first approach has been established. This is not so different from what Pendry has done in the case of electromagnetic waves. In a nutshell, this approach basically is creating a medium that could deviate the sound's path in a controlled manner. Pendry's coordinate transformation technique inspired a group of scientists led by Schurig and Cummer to come up with the idea of a particular metafluid that could do the job [1]. The most important properties they were looking for in different fluids were anisotropy and inhomogeneity. They concluded that if they could cover the object with fluid that could deviate the sound without scattering it, they can make sound pass it without noticing its presence. Since there was no natural fluid with the properties they were looking for, they had to create such material [2]. The novel improvements in Material engineering science and the introduction of metafluids provided them with a great opportunity to test their idea. The transformation acoustic is the unnecessarily hard name that has been given to the new generation of material, which could be used in these kinds of applications since their properties are extensively variable, and it is possible to engineer their properties. This involves, for instance, a two-dimensional plan waveguide made of premium material such as aluminum, where an embedded corrugated frame with drilling a round hollow, to make an anisotropic mass density [3]. Milton and his team completed a thorough study on coordinate transformations in elastic media. Their results were simply a confirmation since, based on their study, suggested that the SUVAT equations are unchanged under coordinate transformation, just like what Pendry found out in case of electromagnetic waves. To test the idea, a group of researchers used a novel tool designed based on engineered materials. Their apparatus was comprised of a director made of aluminum to keep the sound wave in control. They have drilled a circular grooved hole in the aluminum tool to break the mass density isotropy. They wanted their apparatus both in air and underwater [4]. For the underwater efficiency, they had placed an acoustic arrangement that was undescribed, but it was able to create a two-dimensional cloak for sound waves with frequencies higher than 20 kHz, and a two-dimensional plastic gadget with some holes on it was responsible for creating cloaking in the air [5]. The work of a Spanish team has improved this apparatus from Universitat Politècnica de València [6]. They used coatings of metafluids to deviate and control acoustic waves. They coated the obstacle with multiple layers of metafluid by which they were trying to create a density gradient to prevent the waves from scattering. These kinds of materials are known as gradient-index lenses. They are available for both electromagnetic and acoustic waves.

The second kind of solution involves designing a coating that remarkably decreases the whole acoustic scattering waves of an obstacle during a particular frequency band. The first developer of this method that used as a technique for reducing the scattering waves has been done for the electromagnetic field by A. N. [7]. By the same technique, the analysis of plane waves is then applied to the acoustic domain, where these various applications studied and investigated the capability of implementation on surface impedance [8], [9]. In reference [10] designed an essential number of appropriate cylinders of small diameter placed as an acoustic cloak to surround the cylindrical obstacle. But Farhat and Chen suggested a pattern structure has suitable acoustic impedances to make the acoustic scattering reduction at a considerable level for the sphere. Besides functioning these basics of minimization of the scattered field [11], [12] also Sanchis. Presented a new method to dissipate the scattering waves that generated duo to analyze of acoustic waves by using several rings around it [13]. In references [14], [15], the technique of a single isotropic layer can be used around an elastic sphere to accomplish extreme scattering reduction.

Scattering acoustic waves by obstacles (elastic bodies or cavities in solids) immersed in a fluid have been an issue of interest for decades, and this is because of its many practical applications such as acoustic waves tomography, sound radars, fault detection, etc. scattering boundary value problem as Analytical solutions are taken just for obstacles of simple geometries (planes, cylinders, spheres). For another case, numerous approximate approaches have been improved, all having a specified range of applicability depending on incident fields and properties of the obstacle and medium, frequency range, the method of monitoring the scattered field, and other parameters of the problem [16].

From the literature survey, there is ample scope for research in the scattering effect in the cylinder and also scope for optimization to reduce the reflection effect in the cylinder with a cloak. In this thesis, Bat algorithm optimization is used to reduce the scattering effect in the cylinder.

1.2 Contribution

A scattering-cancelation method is followed in this analysis. We investigate the possibility of minimizing acoustic scattering with elastic vibration-based devices. The goal is to decide whether layers of elastic materials could be used to reduce the scattering significantly in the case of a rigid cylinder submitted to regular plane waves. In the case of a multilayer coating, the method used to measure the distributed pressure field is described first. Then, the inverse problem of searching for the parameters of the layers that allow the acoustic scattering to be reduced is revealed. In the case of a bi-layer coating fixed on a rigid ring, results of numerical minimization using a Bat algorithm are provided.

For the elastic layers, optimization techniques were used to identify dimensional and mechanical characteristics that lead to a reduction in scattering.

For each layer, those parameters which constitute the variables of optimization are:

1- The thickness (*h)* of the cloaking material.
2- Poisson's ratio $\nu_{r\theta}$, $\nu_{\theta z}$, and ν_{rz}, of the cloaking material.
3- The mass density ρ of the cloaking material.

1.3 Organizing of Thesis

The arrangement of the thesis can be organized as the following.

1. Chapter two provides a literature survey of scattering waves reduction. In addition, there are some successful electromagnetic cloaking methods which separated in many studies and especially in the study of acoustic waves.
2. Chapter three explains and provides the methodology used for this thesis. Also, in this chapter, there are details of energy transmitted and reflected in the cylinder and derived in the form of a mathematical equation.
3. Experimental verification of the proposed method is demonstrated and described in chapter four. In order to verify the scattering reduction behavior in the cylinder object, MATLAB software was used to create the program to measure and analyze the reflected energy of the acoustics wave in the cylinder with cloaking and without cloaking conditions.
4. Concluding remarks and future work are explained and given in chapter five.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Miles investigated the property of vibration acoustic waves in a simple circular cylinder [17]. In this study, a circular cylinder subjected to plane wave and corresponding results were analyzed and also derived the acoustic propagation details in mathematically. Levine and Schwinger have developed the solution for the reflection coefficient in cylinder duct [18]. The reflected energy of the acoustics wave was analyzed in a circular cylinder, and the magnitude of the reflection is decreased in the radius of the cylinder.

A plane piston in the cylinder duct was tested, and radiating sound energy was analyzed by Ingard [19]. The problem was addressed by observing the results at the open end of the behavior on the acoustic pressure field. The study covered the higher-order modes. Karal found a zero-order mode propagating in an infinite, static, cylindrical structure, and studied the equivalent resistivity and impedance caused by a sudden shift in diameter and a constriction between two ducts [20].

The sound propagation of two semi-infinite parts in a solid, tubular duct was analyzed at the sudden expansion field by Cummings [21]. The main goal of this study mentioned above was the calculation and determination of velocity profiles for both parts and, subsequently, select the most appropriate one to predict the coefficient of reflection. Furthermore, another investigation was conducted to evaluate the rigid and cylindrical elements, exhaust silencers with the mean flow [22]. The mentioned study aimed at the establishment of expression for silencer attenuation with an analysis of convective pressure and mass velocity.

Cargill found a walled cylindrical duct that shifted to a vortex layer and studied the impact of this system of wave propagation of planes [23]. This research applied the technique of Wiener-Hopf to use higher-order modes. This was demonstrated how the existence of a mean flow allows the coefficient of reflection close to the center of the duct to decrease.

In another work, the influence of higher-order modes provided by a rigid-walled expansion champer was studied in detail [24]. This work established a theoretical explanation for the problem by designing it as a lossless, rigid duct driven by pistons. Peat investigated the higher-order modes produced at a discontinuity among two parts of stiff, cylindrical duct [25]. An analogous impedance circuit has been used to evaluate a mode of evanescence and to decide it will work or not. The results of this study revealed that the impedance deviation with frequency is expected.

On the other hand, in an investigation that studied the sound wave radiation produced between two cylindrical ducts, the researchers found that forcing was by a wave incident against the distance, measuring the resulting reflected and transmitted wave fields [26].

F¨oller and Polifke proposed a procedure for determining the amplitudes of reflection and propagation of plane waves that can be scattered in the systems of discontinuous piping [27]. This approach considers a large simulation of the eddy in a cylindrical duct with a single radius change. Externally the test immediately excites seismic waves at each end of the discontinuity. The associations among acoustic waves are described in depth, and the question is solved in determining the wave amplitudes scattered at the discontinuity. The simulation findings are comparable to other observational approaches, which indicate strong consent to the experimental evidence.

Lawrie [28] found a compressible inviscid fluid completely filled an infinite transparent cylindrical structure where the structure had a finite number of ring restrictions and the device. The versatile shell vibrations were modeled utilizing the Donnell-Mushtari motion equations, as Junger et al. reported in [29]. First, there is a restriction of a single ring that is important and has an exact solution that was sought by defining the problem of limit scattering value and resolving the resulting linear structure. The problem was presented as the symmetric and asymmetric problem for two ring constraints.

Stepanishen and Tougas studied the time-dependent pressure for a fluid filled, finite, open ended, cylindrical shell [30]. To push the fluid in the machine, a piston source situated at the shell's inner closed end was used. The piston was supposed to provide an amplitude of the gated sine wave that matched a spatial pattern. The solution was sought by using a Green time-space function to construct a problem with a limit value. Zhang and Abrahams [31] used a modified Wiener-Hopf technique to investigate the sound radiated from a finite fluid-charged cylindrical finite container. The shell was easily immersed in a compressible stagnant stream, and its motions were modeled for a thin, cylindrical shell using the Donnell-Mushtari motion equations. Fluid pressing was created by asymmetric ring stress, between the shell's open ends.

This chapter explores theoretical and experimental literature related to the current study. In recent years, researchers have identified the great potential in metamaterials, as it is possible to engineer their properties to a vast extent. Differing for the material itself, it is possible to create a high mass density gradient in these materials. The gradient-index is what we use in guiding electromagnetic, sound, and lots of other kinds of waves. Not only these materials made us able to do subwavelength imaging and negative refraction, but metafluid coatings can be used to protect our tools and devices from dangerous radiations [32].

There are several cloaking methods today, which is possible only due to the great development in the field of metamaterials [1], [33]–[36]. Cummer and Schurig has been made these concepts extended to acoustic waves [2]. For acoustic pressure waves in a transversely anisotropic material. Another study [37] has investigated the effect of a solid metamaterial. They have tried concentric layers of solid coating to create anisotropy and, eventually, the mass density gradient. Also, other studies have investigated the efficiency of solid conducting layers in creating transparency to the acoustic waves [38].

2.2 An acoustic Scattering Reduction

We primarily aim to conduct education, research and industrial activities in the Scattering is an essential issue in the investigation of the material of phononic crystals and acoustic metamaterials. The scattering of plane waves in the space discomposes challenging subjects, and still, the scattering by elastic objects is the main challenging of all because an acoustic wave divides into different kinds of waves, propagating at distinct speeds, while it enters an elastic object [39]. The topic of scattering reduction by using acoustic cloaking made of metafluids has lately achieved considerable recognition, which is the outcome of its successful applications in the electromagnetic field. There are some successful electromagnetic cloaking methods which are eligible to be used in the case of sound waves:

1- The scattering cancellation technique.
2- The transformation method.
3- Anomalous resonance method.

2.2.1 The Scattering Cancellation Technique

Scattering cancellation is a technique to cloak the object with a material that would cancel the scattering by distributing the scattering in a range of wavelengths, such that scattering does not get resonated anywhere within its wavelength. The concept of acoustic scattering cancellation still has a big importance in the field of scientific literature. It is only since the work of Alù and Engheta (2005) that the study of acoustic scattering cancellation has gained momentum. They used covers from the metamaterial and plasmonic materials to decrease the cross-section of cylindrical and spherical subjects. They anticipated that increasing the physical dimensions of an object might lead to an expansion in its comprehensive scattering cross-section, they also provided numerical examples and physical insights on the importance of a proper design. They demonstrated that coating with lossless metafluids, which have fairly close resonance frequencies to the one of concealing material, could reduce the cross-section of scattering significantly, even in the lack of material loss, which makes the object closely “transparent” to an external observer. They have also studied how this impact is insensitive to the potential losses or other imperfections in structures. This phenomenon can offer several possible implementations in the design of low visible aims, little coupling in densely-packed systems, and non-invasive domain nano-probes. These problems are at present under investigation [7].

In 2007, Alù and Engheta published a paper, in which they have studied how the utilization of metamaterial and homogeneous isotropic plasmonic covers may remarkably reduce the scattered domain from 3D impervious objects of dimensions analogous with the wavelength, efficiently supporting a cloaking technique.

They offered entire simulations for wave propagation with monitoring the cloaking while a plasmonic body is to be cloaked. The outcomes of the study stated that how the “anti-phase” scattering features of suitably constructed plasmonic covers perhaps efficient in causing transparent conducting [40].

An ambitious work has been done in the year 2009. A group led by Andrea Alu claimed it is possible to cloak a sensor in a way it doesn't lose its sensitivity. He wanted to make an apparatus that deviates the radiation path in a way that it couldn't hit the sensor directly, yet the sensor can detect it. Not only detect but also it would be able to measure everything it was meant to measure in the absence of the coating. If he succeeds, the result would be a sensing system that could revolutionize engineering, optics, biology, and physics' experimental devices [41].

D. Rainwater and A. Kerkhoff, described the experimental validation of standalone cloak for a 3D body, accomplished by using the plasmonic cloaking method to a finite cylinder about two wavelengths long lightened by microwave radiation. Their results offered that strong and robust scattering suppressing can be gotten over a temperately broad frequency range, low dependent on lightened and observation positions. Furthermore, it is clear that the overall near-field and far-field investigational measurements are in complete agreement with the all scattering cross-section (SCS) forecasted from their complete-wave numerical simulations of the realized plasmonic cloak stated [42] as shown in Figure 2.1.

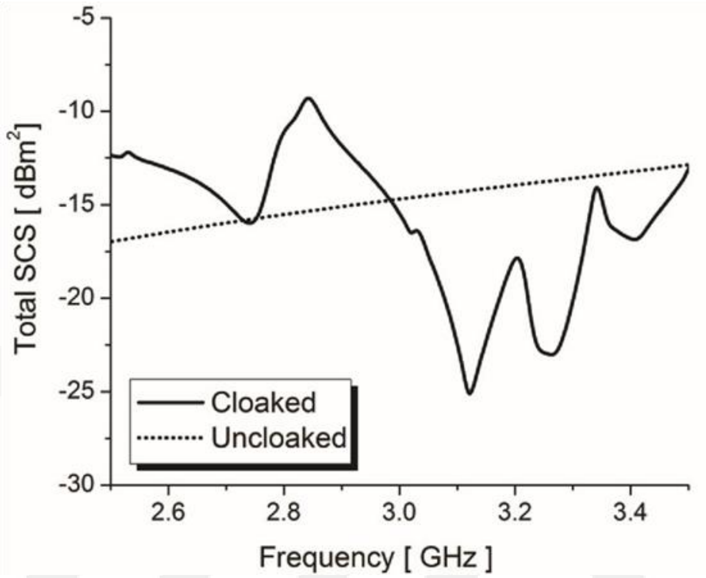

Figure 2.1: The predicted SCS using full-wave simulations of different conditions over the design frequency for ordinary incidence brightness [42].

In 2006 Yu.I. Bobrovnitski researched the potentiality of achieving and make layers of acoustic cloaks with tailored surface reluctance. They proposed a modern theoretical solution to the sound scattering problem. It is appropriate to elastic scatterers of any arrangement in a fluid medium that may be limited and inhomogeneous. The solution is written in expressions of three impedance matrices that are recognized with respect to the scatterer intermediate interface and entirely characterize the scattered field. Generic properties of the solution, for example, the symmetry of the scattering matrices, are considered. Some new suitable representations of the scattered domain are also presented. The suggested solution is carried out to three types of practical problems of acoustic scattering and absorption to getting new results-Most of these problems for an acoustically transparent object and the better absorber. The new solutions for all these problems are formed in expressions of the in vacuo surface reluctance of the scatterer.

Bobrovnitskii suggested that these solutions could be fulfilled by the use of thin active coatings located on the scattered surface and utilizing the active reluctance matching approach [8].

Also Yu.I. Bobrovnitskii in 2007 presented a new method to passive acoustic cloaking, which can be an alternative to the popular method of transformation optics. An alternative passive approach, which, in the author's view, is more reasonable for practical application. Bobrovnitskii showed that the invisibility problem could be resolved by utilizing a thin passive coating whose surface reluctance is near to and equal to the surface impedances of the perfectly transparent object for which clear governing equations are done. This is the thin coating that suggested could provide impedances with controlled accuracy. The results of the computer simulation presented expression that most ideal invisibility to echolocation system can be accomplished employ coatings of very simple construction [43].

Remarkably, Cummer et al. and Bogdan-Ioan Popaobserved that three-dimensional sound waves cloak can also be used in case of stress waves within a liquid because the wave equation is invariant under coordinate transformations and both pressure waves and sound waves have the same equation. Through acoustic waves scattering theory, they derived the bulk modulus and mass density of a cloaking shell, which is a spherical casing that can prevent random scatterings. They confirmed by their calculations the velocity and pressure waves could easily deviate and prevented from hitting the object, just like the way cloaking shells would do. This cloaking case needs a radially bulk modulus with a mass density gradient and major axes of the spherical coordinate. This three-dimensional cloaking shell refers to that such reflectionless solutions may also occur for another wave system, which is not isomorphic with electromagnetics [44].

Pai-Yen Chen and Mohamed Farhat, in 2011, researched the possibility of deviating sound waves using a film of a metamaterial. The most important difference here is the fact that former cloaking devices were so thick, and a large amount of metamaterial was needed, which respectively made it harder to keep anisotropy. In this research, they introduced a thinner shell that could do the job. Figure 2.2 is a schematic view of the shell they have proposed [11].

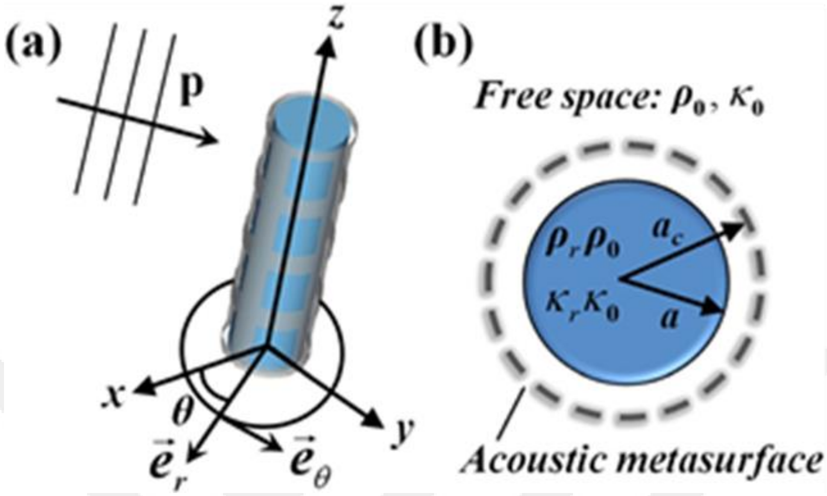

Figure 2.2: Sketch (a) demonstrates a plane wave propagating in the direction of increasing "y" and perpendicular to 'z' axis along which there is a concentrically patterned cylindrical barrier schematically. While figure (b) illustrates the exact same configuration but in the plane normal to the z-axis, where the radius of the cylindrical barrier is exposed and is ‘a’, moreover, the wave's metasurface is expressed by dashed lines [11].

Even though cloaking phenomena has been established over a firm bedrock of theory, and probably we are sure that it is possible. Yet, in practice, everything is different; there are lots of difficulties in engineering materials that could bring all the necessary properties together. It could not be possible or have serious limitations up to the best of our knowledge. On the other hand, the novel technique that Chen and Alu have proposed has proved to be successful in the case of subjects with reasonable size [45]. Their technique has decreased the scattering cross-section and the scattering significantly. To this end, they have used a film of metamaterial, which could provide a fair surface reactance, which had nothing short of the cloaking created by thick metamaterials. The key was design. To determine what surface reactance can create the desired quality, they have used the frequency of vibrations in the surface of bulk metamaterial, which could cause the desired cloaking [46].

The idea of a cloaking device goes back to Leonhardt. He proposed it is possible to make something invisible if we could control the light's path in a way that it moves from the sides of the subject but not through. This way, the object is invisible because there is no light reflected off it. The geometrical optics was the field that made Leonhardt believe invisibility is possible. By the development of metamaterials and geometrical optics, Leonhardt achieved invisibility in electromagnetic waves. Today, the same recipe may be applicable for acoustic waves and all other kinds of waves [47].

Marc Briane and et al. investigated and improvemented the electromagnetic cloaking which studied by Leonhardt that offered by Helmholtz equation in two dimensional space, and this work is possible to achieving it by using special conditions of equations which can offer the response of elastodynamic in different types of composite materials. Some of elastic material is characterized by microstructure under the normal scale of formatting the continuum field. If we have bandwidth of elastic plane waves with rang of frequencies, it is possible to create devices made of layers of elastic cloaking invisible that can dissipate the scattering waves around the object that it propagate in homogeneous field. There are another equation of elastodynamic possess their configuration under technique of transformation. Most of the equations under technique of transformation have form invariant in the field of space and time. They showed that equations of elastodynamic retain this invariant which controlled by transformation technique of space and time. Also they presented the spatial arguments which displayed in form of transformation technique of time harmonic dependence [48].

Since the mid-2000s, a major part of the scientific society has come to believe that the way to cloaking is what Cummer et al. presented in their work. Based on their paper, in 2D, acoustics satisfy a particular form of Maxwell equations in liquids. Not only the same equation, but it's true about the boundary conditions, as well. We emphasize the existence of transformation-type solutions for the two-dimensional acoustic wave equations with anisotropic mass by time-harmonic emulation of acoustic wave cloaking. We explain the potentialities of experimentally demonstrating acoustic wave cloaking and examine why this special equivalence of sound waves and electromagnetics happens only in two-dimensional [2].

Different theories exist in the literature regarding acoustic cloaking, where Andrew N. Norris presented that the most commonly accepted definition for the acoustic cloak. According to Norris, a shell which is covering a limited area is called an acoustic cloak if all the acoustic signals whose path enters the shell, deviate from their original path as they reach the shell, and nothing hits anything from inside of the shell. Acoustic cloaking later has been developed using the same method Pendry once had invented it for electromagnetic cloaking known as transformation optics, but in the case of acoustics, it is called transformation acoustics technology.

They showed that the main property in cloaking is simply anisotropy: either the mechanical stiffness or the mass density or both. If the stiffness is isotropic, identical to a fluid with a singular bulk modulus, then the inertial density should be infinite at the internal surface of the cloak. This needs an infinitely massive cloak. They showed that perfect cloaking could be completed with finite mass through using anisotropic stiffness. The generic category of anisotropic material required is known as Penta mode materials. If the transformation deterioration gradient is symmetric, then the Penta mode materials parameters are explicit. Otherwise, its characteristics depend on stress, such as tensor that satisfies a static equilibrium equation. For an obtained transformation mapping, the materials composition of the cloak is not uniquely realized, but the phase speed and wave velocity of the pseudo-sound waves in the cloak are unique [49].

Based on research done by Norris, acoustic metafluids are a group of fluids with very similar properties. The array made of layers of these materials has the desired properties which have been mentioned lots of times above. The coordinate transformation technique has proved to be useful both for 1D and 3D cloaking. There is no difference between the fluid in the transformation region and the fluid elsewhere. Norris and his team identified a few uncommon properties in meta-fluids. Figure 2.3, Figure 2.4 and Figure 2.5 are demonstrating the unusual surface tension of Aluminum-based meta-fluid [50].

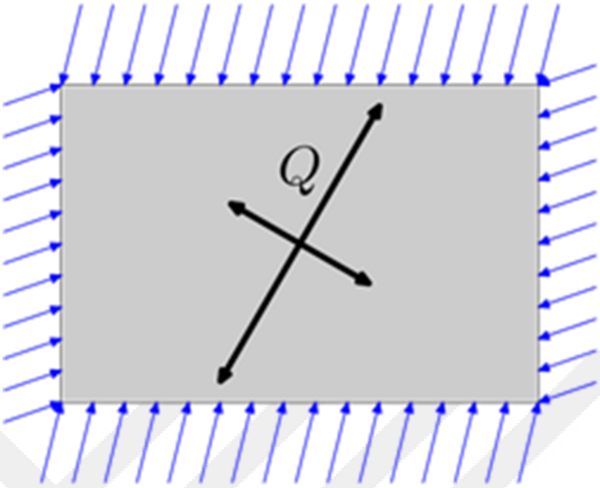

Figure 2.3: Demonstrates a chunk of meta fluid which is stable due to its ultrahigh surface tension[50].

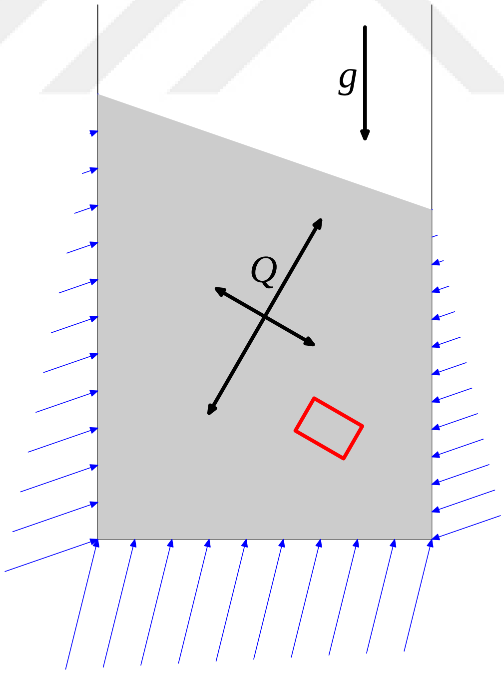

Figure 2.4: Shows the very meta fluid in the former figure in the presence of gravity. As it's clear in the figure, the surface of the meta fluid is not flat as it was expected for meta fluids[50].

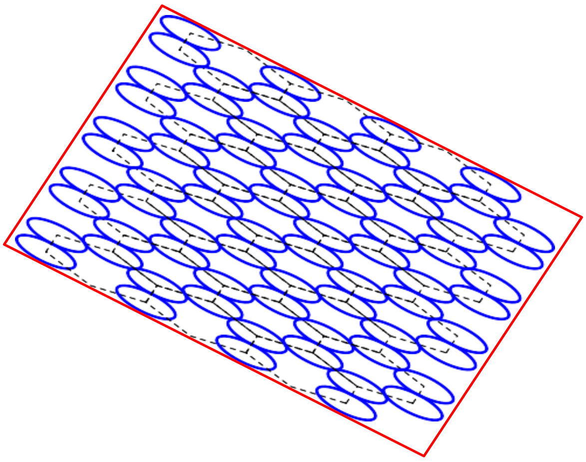

Figure 2.5: It is a schematic picture of the microstructure of the metafluid slice depicted in recent figures. As it is clear in the picture, meta fluid is comprised of microscopic hexagonal cells. Also, each cell contains six bead-like structures, and each bead is in direct contact with three similar beads in 2D representation. The red dashed hexagonal structure resembles the forces between each bead [50].

The process of fabricating acoustic meta-fluids has changed a lot since the first time they have been developed. Most of the design techniques we use today have been developed just recently. Moreover, meta-fluid degrees of freedom (DOF) is much different from usual materials as their DOF depends strictly on the stress-strain tensor Q, while it is respectively function of velocity (V). The results of their study suggested that the deformation gradient (F) has a strong dependence on mass anisotropy, which in turn is determined by the elasticity and pentagonal shape microstructure of the material. Pendry has tried to optimize the finite deformation parameters. He pointed out to the degrees of freedom of Q as the possible pace to make the desired optimizations. Later, Norris proposed the possibility of using elastic material layers as acoustic materials using the transformational technique. The exceptional property of matter with pentagonal microstructure is the mass density, which is homogenous everywhere throughout the material. Moreover, their elasticity, which is because of the low deformation resistance in their potential modes, makes them eligible choices for cloaking meta-fluid. Nevertheless, there are too many practical challenges toward obtaining pentamodal material [50].

Graeme W. Milton has shown that any assumed positive definite fourth-order tensor gratifying the typical symmetries of elasticity tensors can be recognized as the efficient elasticity tensor of a two-phase combined comprised of an adequately compliant isotropic phase and an adequately rigid isotropic phase arranged in an appropriate microstructure. The constructing blocks for building this composite are what we denominate extremal materials. These are combinations of the two phases which are remarkably stiff to a set of arbitrarily assumed stresses and, at the same time, are remarkably compliant to any orthogonal stress. A correctly chosen subsection of the extremal materials is coated together to form the combined with elasticity tensor matching the assumed tensor. There are too many factors limiting the efficiency of acoustic cloaks. Most important of those parameters are the specific material properties which require and the significant decrease in close range resonance. The acoustic cancelation method is the next most interesting alternative that may be evaluated as we discuss acoustic cloaking. Scattering is the most natural phenomenon which should be expected when one tries to deviate a wave, during which the wave loses its energy and, respectively, the information it carries. The acoustic cancelation method is a technique that decreases the amount of scattering by selecting proper layers of material. Generally, elastic material has proved to be useful in these kinds of situations.

Nevertheless, they are useful only for objects with limited sizes. But in those cases, elastic material can reduce the scattering up to several orders of magnitude. This method has been tried for obstacles with cylindrical and spherical shapes, and it proved to cause significant frequency alterations. Hopefully, this method can be extended to obstacles with more complicated shapes [51].

Andrea Alù and Nader Engheta in 2007 developed the concept of using plasmonic covers for cloaking an isolated conducting, insulating sphere or plasmonic through scattering withdrawal, here they extend this idea by studying the potentiality of cloaking multiple objects located in near proximity of each other or combined to form one object. They showed how the existence of properly planned covers significantly decreases the coupling between the single particles, hence providing the opportunity of creation gatherings of “cloaked” and objects transparent to the impinging radiation even in the case of the total physical size of the structure is sensibly greater than the wavelength [52].

Andrea Alù and Nader Engheta in 2008 theoretically suggested the possibility of utilizing a multilayered plasmonic layer as a cloak for decreasing the overall scattering cross-section of particles, concurrently at various frequencies in the optical domain. By using the frequency scattering of plasmonic materials and their fundamental negative polarizability, it is presented, numerical simulations, and theoretically, how covering conducting object of a specified size with this multilayered cloak may decrease its ‘‘visibility’’ by numerous orders of magnitude simultaneously at various frequencies [53].

Xiaoming Zhou, Gengkai Hu, and Tianjian Lu presented analytically study for the elastic waves transparency phenomenon of a coated solid sphere surrounded in a fluid medium or a host solid by using incident compressional waves [54] as shown in Figure 2.6.

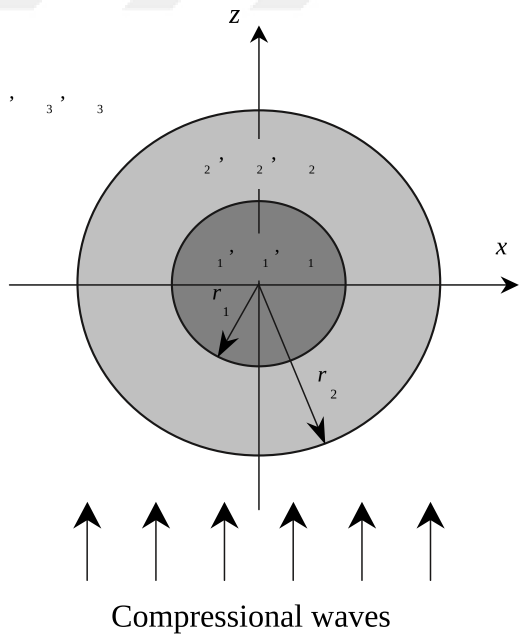

Figure 2.6: A coated sphere embedded in a host medium and illuminated by a plane compressional wave[54].

They offered in the Rayleigh limit, derivation of the first three scattering coefficients and a particularly useful sphere can exemplify the layered sphere. They used Berryman’s formula to estimate the density parameters and active modulus of the coated sphere (an assemblage of the layered sphere method). The resonance phenomenon and relatively resonance effect of a coated sphere caused by mass density were also investigated. The full-wave computations with Numerical results reveal that the assumed quasi-static conditions provide an excellent estimation of the resonance phenomena and transparency in the dynamic case [54].

2.2.2 The Transformation Method

Transformation optics and transformation acoustics enabled us to deviate different waves to accomplish complete invisibility. This technique needs engineered materials with high degrees of anisotropy and highly controllable properties to deviate the respective wave in a controlled manner, with the minimum scattering and loss of information. Ulf Leonhardt was the first one who has suggested that we can invent an invisibility cloak if we can control the path in which the light moves. This way, it goes around an object without hitting it, just like there is nothing there to hit. It's not only the practical shortcomings that are blocking the way of achieving the perfect invisibility, but also the wave nature of light theoretically makes it impossible to achieve 100% invisibility. In this report, we have tried to build upon the available data to enhance the performance of acoustic cloaking devices in the limits of transformation acoustics. Today, it has been made possible, in the shadow of recent developments of metamaterials, to make obstacles of the order of several wavelengths of the incident radiation totally invisible.

Moreover, the method can be expanded to make the invisibility possible for various kinds of incident radiations [47]. Most recently, a team led by Shurig, have achieved the practical cloaking. They have reported that, by reducing the scattering and the shadow, they have achieved the state where the object and cloak together could vanish totally [55].

Chan et al. investigated the possibility of creating a duality between Maxwell wave equations and the equations of acoustic waves to achieve the 2D acoustic cloaking that has been proposed by Cummer in 2007. They reported that there exists a duality such that it is possible to map the equation of acoustic waves to the Maxwell equation in 3D, which means it is possible to use the transformation method in the case of sound waves. Figure 2.7 simply demonstrates the phenomena. Moreover, Bessel functions are the solution of the wave equation in case there is the duality aforementioned. [56].

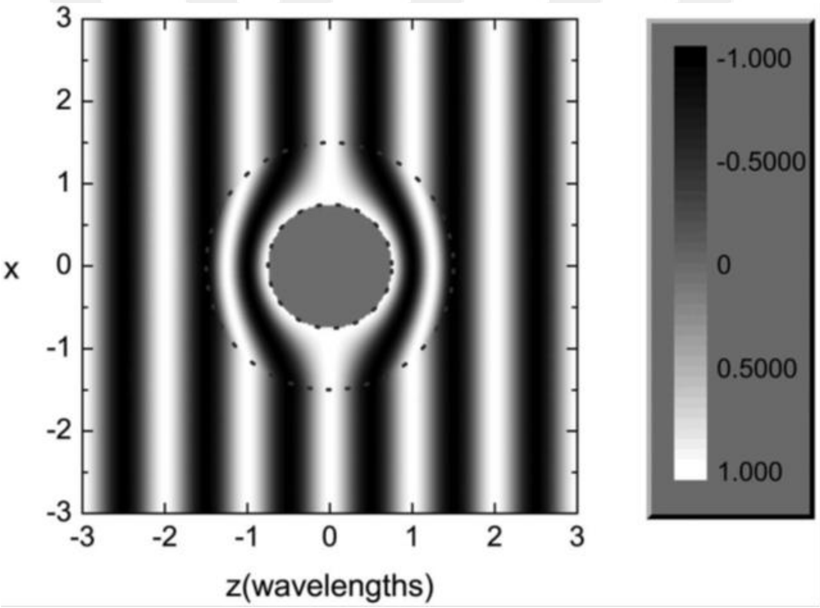

Figure 2.7: It is the schematic view of three-dimensional acoustic cloaking. It demonstrates the acoustic pressure view in the x-z plane, where the z-axis is the wavelength. 2 dotted circles determine the span of the acoustic cloaking [56].

As we have discussed before, to achieve complete invisibility, we need a material with infinite density for the last layer of our coating, which makes it really hard since there is no such material. Achieving the total cloaking phenomenon is a challenge in front of material science.

D. Schurig et al. studied the possible method for calculation of the material properties related to a coordinate transformation and utilized them to achieve an appropriate ray tracing. They presented a model of cylindrical and spherical cloaks, and they found that the transformation method can be acceptable and independent verification may not be required. It can be observed that the electromagnetic waves will do much more by using the transformation to the rays in the initial space. They believed that an optical transformation would show to be an effective approach. Simultaneously with improving metamaterial technology, it must lead to the investigation of tools that would be complicated, if not improbable, to consider and make the other novel paths [57].

Based on a coordinate transformation method, J. B. Pendry. have stated electromagnetically anisotropic and inhomogeneous cases that, in theory, totally shield an inner structure of arbitrary scope from electromagnetic areas without troubling the external fields. Steven A. Cummer and others reported full-wave simulations of the cylindrical form of this cloaking structure utilizing the ideal and nonideal electromagnetic parameters in work to understand the challenges of achieving such a structure in practice. The simulations show that the implementation of the electromagnetic cloaking structure is not particularly sensitive to modest permittivity and permeability differences. This is in distinction to other functions of engineered electromagnetic materials, for example, subwavelength concentrating utilizing negative refractive index materials. The cloaking implementation degrades smoothly with improving loss, and efficient low-reflection shielding can be completed with a cylindrical shell consist of an eight homogeneous layer approximation of the perfect continuous medium [58].

Similar ideas have been considered for the conductivity equations by Allan Greenleaf, Matti Lassas, and Gunther Uhlmann. They emphasized that in the previous counterexamples, the conductivity tensor is not limited below. Nevertheless, in practice, several objects are formed to be completely insulating, which matches in mathematical conditions to zero conductivity. This means, naturally, that the conductivity is very small that it can be formed to be zero when compared to actual objects within measurement accuracy. In special, in reluctance tomography, an ill-posed issue, the measurement accuracy is quite poor. So, even wisely, low conductivity materials, in special those that are placed far from measurement electrodes, may provide rise to measurements identical to perfectly insulating materials. The counterexamples offered in their paper might present an explanation of influences that may be seen in functional measurement configurations. In actual, for applications of electrical impedance tomography quite roughly speaking, we can assume a case wherein a patient's body, there are cancerous tumors that are covered with little conductivity, anisotropic tissue. In this situation, the tumor may seem in measurements is healthy tissue [59].

Many researchers achieved invisibility cloaking in acoustic plan waves by using the mapping to the conductivity equations. Different wave manipulation strategies such as the rotation and concentrator coating can be simply derived utilizing the transformation media idea.

Marco Rahm, David Schurig, and others offered a suitable material design of a square- designed cloak and an electromagnetic domain concentrator established on formula-fixed transformations of Maxwell's equations. The electromagnetic attitude of the devices was modeled by using a solver of a 2D FE method. In inversion to previous papers and other investigations, the asymmetry was used for the simulation of the cloaking method. Both of the introduced optical devices represent the potency of the general method of form-fixed coordinate transformations of Maxwell's equations for the model of electromagnetic substances with a well-described functionality. The method mentioned above provides the opportunity of the selection from an unlimited set of possible transformations and therefore allows having an appropriate tool for the optical domains with the formerly impossible electromagnetic performance [60].

Huanyang Chen and C. T. Chan suggested a way to manage electromagnetic waves by presenting a rotation mapping of coordinates that should be achieved by a specific transformation of permeability and permittivity of a shell surrounding a bounded domain. Inside the bounded domain, the knowledge from outside will appear as if it comes from a distinct angle. Numerical simulations were achieved to illustrate these properties [61].

There are many designs to fulfill the invisibility cloak for electromagnetic waves. Wenshan Cai, Uday K. Chettiar, and others suggested an electromagnetic cloak by using high-order transformation to make easy rather than discontinuous moduli at the external interface. By this method, the unacceptable scattering is totally eliminated in the limit of geometric optics, even for cloaks utilizing nonmagnetic materials to simplify the application. They used this scheme to the nonmagnetic cylindrical cloak and explained that the scattered domain is decreased by approximately an order of magnitude in a cloak with optimal condition quadratic transformation contrasted to that with the normal linear compression. This nonmagnetic cloak and decreased scattering give us one step nearer to accomplishing an existing cloaking device at optical frequencies [62].

Huang et al. investigated the behavior of an electromagnetic cylindrical cloak by accomplishing the radius-dependent and anisotropic material through layered formations of homogeneous isotropic materials. The work of the cylindrical cloak has been shown through the strict computation of the electromagnetic wave scattering, which exhibits the power-flow and low-scattering bending nature of the suitably designed cloaking structure. This method is analogous with the metamaterial-based cloak in terms of electromagnetic field allocation, the forward and backward electromagnetic scattering reductions as well as the power flow. Their proposal has no requisites of any inhomogeneity or anisotropy of the material constitutive parameters, which generally require metamaterials and structured inclusions to achieve. Like this cloak is possible to be completed by thin layers of usual materials or composites, hence may lead to an easier track to an experimental showing of electromagnetic wave cloaking, mainly in the optical scale [63] as shown in Figure 2.8.

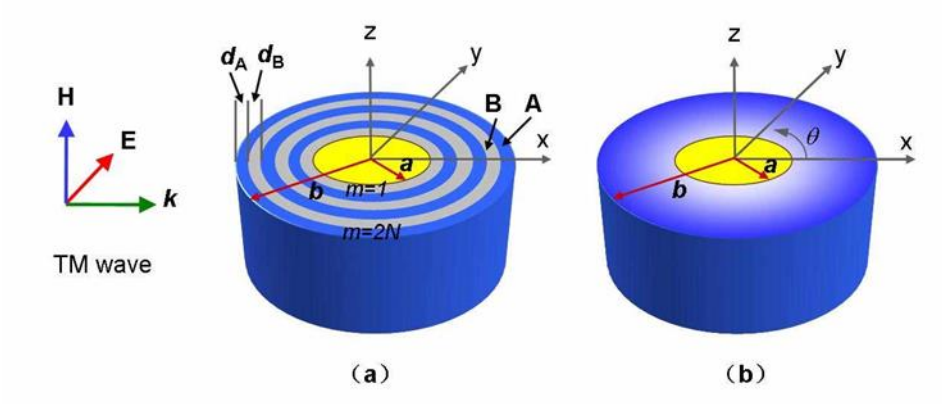

Figure 2.8: Presentation of transverse magnetic [TM] wave on a cylinder (yellow colored) shelled with (a) concentric layers structure with substituting A and B dielectric layers, (b) corresponding anisotropic cylindrical medium depending on the radius of a cylindrical shell and anisotropic parameters of the material. The inner and outer radius of shells is presented by a and b, respectively[63].

Pendry's Coordinate transformation technique has its roots in the fact that electromagnetic field equations do have some gauge symmetries due to which it does not change by a coordinate transformation. So the technique can be applied for all waves that demonstrate those symmetries. Unfortunately, most of the classical waves do vary under such transformations. The thing that Willis showed was the fact that elastic waves relation do vary under a coordinate transformation. However, they were able to modify those equations in a way that the new equations not only were the general form of elastodynamic equations but also they were invariant under curvilinear transformations. So they concluded that invisibility could be achieved for elastics waves too [48].

They investigated the coordinate transformation of the elastodynamic EQs. The result was surprising, as, in new coordinates, the mass density was anisotropic itself. The new coordinates seemed to be a more natural choice of coordinates for elastodynamic equations. In new coordinates, the momentum was coupled to strain in addition to velocity, and velocity, respectively, was a function of stress. Milton was convinced that the new equations were the equations that must be used in the case of composite materials. Nevertheless, to make the theory work, there should be a fluid coating with anisotropic density and compressibility, which are aligned radially. In this scenario, the final layer of coating must have an infinite density, to make invisibility possible. Eventually, it is possible to hide an obstacle from the elastic waves if one can find a material with proper moduli. The most important thing is to determine the correct frequency. Then the natural question to ask if the new equations are invariant under all possible coordinate transformations or an only particular group of transformation can keep the equations unchanged. The answer depends on the underlying symmetries. Equations are invariant only under particular groups of transformations that are about the symmetrical parts of the equations. So equations are invariant under global time-dependent curvilinear transformation groups. Here we are talking about the mathematical concept of the group [48].

2.2.3 The Anomalous Resonance Method

The anomalous resonance technique requires an appropriate placing for scattering devices, which may be made of passive or active material in the region, which we are trying to cloak. Nicorovici et al. have investigated the invisibility for the fields that may present irregular resonating spots, and his results were positive, which means it is possible to deviate the fields with not homogeneous distributions in a way that they can be guided around an obstacle without noticing its presence. However, it is only possible in case the source of the anomaly is one of the most simple resonating sources like pointlike dipoles or polarized 1D segment. Moreover, the internal anomaly source must be able to cancel the effect of other external sources, which is obvious since it is the only way that source can cause an anomaly in the first place. This kind of cloaking happens only in a particular distance from an anomaly source, where we can assume a semi-static field of the anomaly source. They estimated one could expect a lensing effect in the distance about d/2 far from the anomaly source, where d is the size of the cloaking lens itself [35].

N. A. Nicorovici and R. C. McPhedran analyzed the two-dimensional possible around a layered cylinder located in a non-uniform region. In two special situations, the system works as if the core of the cylinder were increased with the absence of the shell. These are when the shell dielectric constant is the negative of either the matrix dielectric constant or the core dielectric constant. While the shell dielectric constants have a small imaginary part, the domain can show big fluctuations that stay localized nearby the surface of the layered cylinder [64].

Nguyen et al. studied cloaking via irregular local resonance for a subclass of completed means called increased complementary media. This type is fine adequate to allow us to hide an arbitrary source focused on an arbitrary smooth limited ramified of codimension one located arbitrarily via anomalous localized resonance; the cloak is autonomous of the source. Three properties are recognized for doubly complementary modes. Cloaking via anomalous localized resonance appears if and only if the power blows up. The power blows up if the source is placed close to the plasmonic structure. The power remains limited if the source is far afield from the plasmonic structure. The blow-up of the power is organized for reflecting the complementary medium. The evidence is based on several new observations and concepts. One of the problems is to handle localized resonance. To this end, we expand the reflecting and eliminating localized singularity methods introduced and realize the separation of variables for Cauchy problems for a typical shell [65].

Kohn et al. introduced a new technique based on a pair of dual variational parameters and use it to several non-radial examples. A body of literature has improved in connection with “cloaking by using anomalous localized resonance.” The mathematical core of the matter includes the work of a divergence-forms elliptic equations in the plane, div [a(x) grad u(x)] = f (x). The complex valued factor has a matrix-shell-core geometry, and real part equal to one in the matrix and the core, and mines one in the shell, one is concerned in understanding the resonant work of the solution as the imaginary part of a(x) reduces to zero. Most analytical behavior in this field has depended on the separation of variables and therefore has been constrained to radial geometries. In their examples, as in the radial situation, the spatial position of the source f represents a crucial role in defining whether or not resonance happens [66].

Habib Ammari, Giulio Ciraolo and Hyeonbae Kang suggested that If one covers the obstacle of dielectric matter with a layer comprised of plasmonic matter with a negligible loss factor, and creates an irregular resonating field, then this can reduce the loss factor to something with limit going to zero. Moreover, for a coating made of a two-dimensional dielectric, the loss factor could be a nonpositive constant, then cloaking by use anomalous localized resonance occurs, and if the coated structure is spherical (3D), then cloaking by use anomalous localized resonance does not occur. Their work aimed to show that cloaking by use anomalous localized resonance uses place if the coating layer has an appropriate dielectric tensor with a proper anisotropy index [67].

Daewon Chung and Hyeonbae Kang investigated cloaking by using anomalous localized resonance on the body where the core and the shell are irregular ellipses. They adjusted the spectral method (SE) improved to show that there is an analytical elliptic radius such that for any source reinforced inside the critical radius, weak cloaking by using anomalous localized resonance happens and for any source reinforced outside it cloaking by using anomalous localized resonance does not happen. The formula for the critical radius accepts different forms according to the ratio of the elliptic radii.

They suggested another natural method to coat the elliptic hearts (or hearts of general shape). They chose the form of the shell as an extension of the hear [$\Omega = \delta D$] for several constants $\delta > 1$. In this situation, it would be completely interesting to get the critical field containing the heart and shell such that for any source supported inside the critical field weak cloaking by using anomalous localized resonance takes place and for any source supported outside it, cloaking by using anomalous localized resonance does not take place. In the irregular case, the analytical radius determines the critical field. Their computations did not apply to the dilation arrangement since two distinct elliptic coordinates are needed [68].

Sanghyeon Yu and Mikyoung Lim considered an unconventional superlens and exhibited that it shows a new type of shielding effect. In contrast to the typical shielding device, the new shielding influence does not need any material surrounding the field to be shielded. They considered a quasistatic regime in two-dimensional space. In their method, the Möbius map Φ is principally used, and it can be shown in the form of the bipolar coordinates. They expected that it would be possible to expand their result to the three-dimensional quasistatic condition by using the coordinates of bispherical. It would also be interesting to expand it to general electromagnetic waves by assuming the full Maxwell equations [69].

Habib Ammari and Giulio Ciraolo presented for the first time a mathematical justification of cloaking by using anomalous localized resonance in the situation of general source terms. In specific, they found an explicit necessary and adequate state on the source term for cloaking by using anomalous localized resonance to happen. In the situation of an annulus structure, they showed that weak cloaking by using anomalous localized resonance takes place for almost any source reinforced inside the critical radius. They also found a sufficient state on the Fourier coefficients of the Newtonian potential of the source function for cloaking by using anomalous localized resonance to occur. It would be completely interesting to simplify whether weak cloaking by using anomalous localized resonance implies it, or not, for sources whose verification does not completely enclose the annulus. Their results and techniques of this work can be directly extended to the three-dimensional case [70].

Kazunori Andoy and Hyeonbae Kang investigated anomalous localized resonance on the circular coated configuration and cloaking because of it in the context of elastostatic systems. The structure involves the circular core and constant Lame coefficients and the circular shell with negative Lame parameters related to those of the core. They showed that there is a nonzero number k0 governed by Lame parameters like that two nonempty eigenvalue successions of the Neumann[Poincare operator related to the structure converge to k0 and -k0, respectively, and develop precise asymptotic of the convergence. They then showed by qualitative approximations based on the asymptotics of eigenvalues that hiding by anomalous localized resonance happens if and only if the dipole-kind source lies in the critical radii specified by radii of the shell and the heart [71].

Daniel Onofrei1 and Andrew E. Thaler studied the phenomenon of anomalous localized resonance in the situation of an infinite slab of the nonmagnetic and homogeneous material (μ = 1) with permittivity [ϵs = −1−iδ] for a few small loss [δ ≪ 1] enclosed by homogeneous, nonmagnetic, positive media. This phenomenon of anomalous localized resonance is detected at the interface between negative material parameters and materials with positive and is described by the fact that when a specified source is located near the interface, the magnetic and electric region start to have very large and fast oscillations nearby the interface as the absorption in the materials come to be very small while they stay regular and smooth away from the interface. They clearly characterized the specified value of the result between frequency and the width of the slab beyond, while the anomalous localized resonance phenomenon does not analyze and occur the state when the phenomenon is recognized. Furthermore, they also made sources for which the anomalous localized resonance phenomenon never appears [72].

Henrik Kettunen, Matti Lassas, and Petri Ola studied anomalous localized resonance and formulated a new case, the weak anomalous resonance, where the velocity of the blow up of regions may be slower. Using this idea, they studied the blow up of regions in the attendance of negative material parameters without use quasi-static approximation. They gave simple geometric cases under which weak Anomalous Resonance or Anomalous Localized Resonance that may, or may not seem. Especially, they showed that in a situation of a curved layer of negative material with an accurately convex boundary, neither Anomalous Localized

Resonance nor weak Anomalous Resonance appears with non-zero frequencies [73].

Hongjie Li and Hongyu Liu considered the anomalous localized resonance because of a plasmonic construction for the elastostatic system in R2. The plasmonic structure needs a common core-shell-matrix method with the metamaterial placed in the shell. If there are no cores, they showed that resonance happens for a very broad type of source. If the core was not empty and of an arbitrary form, they showed that there is a critical radius like that anomalous localized resonance occurs. Their case is based on a variational method by using the dual variational principles and primal for the elastostatic system, along with the construction of appropriate test functions [74].

Hongjie Li, Jinhong Li, and Hongyu Liuin considered the plasmonic resonance and cloaking because of anomalous localized resonance in the case of linear elasticity. The critical ingredient is agreeing with the attendance of negative elastic materials, that can break the strong convexity situations satisfied by the Lam´e parameters. The resonant area shows highly oscillatory behavior that is revealed by the blow up of the energy dissipation in the underlying elastic approach as the loss parameter becomes zero. The choice of the negative Lam´e parameters for the plasmonic structures is crucial for the occurrence of the resonances. In the case of the spherical geometric setup, they derived all the possible plasmonic forms that may induce resonances. These cases include the present ones studied in the literature as a particular case in the current article. In addition, they proved the plasmonic resonances for those recently found structures in the finite frequency regime. Before their results, the plasmonic resonance has been explored only for elastostatics. Therefore, their results validate the quasi-static calculation of the plasmonic resonance for completely small elastic inclusions. Then, as an application of the lately found structures, they constructed a plasmonic system of the core-shell-matrix formula that can make cloaking because of anomalous localized resonance in the quasi-static management. This also involves the present study in the literature as a special case. They have made a combination use of asymptotic analysis, Fourier techniques, spectral analysis, as well as layer potential technique. The framework improved may be used to derive the cloaking a plasmonic resonance for the elliptic geometry by using the elliptical coordinate system. Therefore, one would confront many more methods and delicate analysis. The recently found plasmonic structures may obtain interesting applications in other fields like imaging resolution enhancement [75].

Kazunori Ando1, and Yong Ji, investigated in the first time spectral properties of the Neumann–Poincare factor for the Lame method of elastostatics. They showed that the elastostatics Neumann–Poincare factor might be symmetrized in the same form as that for the Laplace operator. They then showed that elastostatics Neumann–Poincare operator is not compact as in smooth fields, it is polynomials function compact, and its spectrum on two-dimensional smooth domains involves eigenvalues that accumulate to two different points specified by the Lame constants. They then derived Eigenfunctions and explicitly eigenvalues on ellipses and discs. By these resonances occurring at eigenvalues are assumed [76].

2.3 Bat Algorithim Optimization

Design optimization makes an essential element for every design difficulty in industry and engineering. Optimization of structural design concentrates on getting the best and effective answers for complicated structural design difficulties in dynamic complex loading patterns with nonlinear multiple forces. Those restrictions usually include thousands and millions of parts with stringent restrictions on geometry, stress along with service and loading conditions. The purpose is not simply to reduce materials usage and cost, but additionally to maximize their lifetime service and performance. All those designs are of practical and scientific significance[89].

Nevertheless, most structural layout optimization difficulties are very multimodal and nonlinear what include noise, and therefore they are usually NP-hard.

Obtaining algorithms that are correct and functionally effective is normally challenging, if not improbable. In reality, the selection of an algorithm needs comprehensive knowledge and expertise of the problem. Yet there is no undertaking that best or equivalent suboptimal resolution could be established.

Met heuristic algorithms include swarm intelligence and evolutionary algorithms that are nowadays becoming important techniques for resolving various difficult difficulties and primarily real-world engineering difficulties. In the following sections, various swarm intelligence algorithms would be highlighted, accompanied by a summary, before reveling their utilization forms in various problem areas. Figure 2.9 presents a fundamental hierarchy and classification of algorithms, such as swarm intelligence-based, which are explained in this study. Novel algorithms are as well rising lately, such as the firefly also harmony search algorithm. The harmony search was inspirited through the composing of music piece improvising process. However, the firefly algorithm was formed according to fireflies flashing behavior. Each of these algorithms has definite benefits and drawbacks. Such as, simulating annealing could nearly undertake to get the best answers if the cooling method is slow and simulation is working long sufficiently; though, a precise improvement in parameters influence the convergence speed to find the optimization method [88]. A fundamental question is if it is likely to merge the main benefits of those algorithms and attempt to form a possibly more beneficial algorithm.

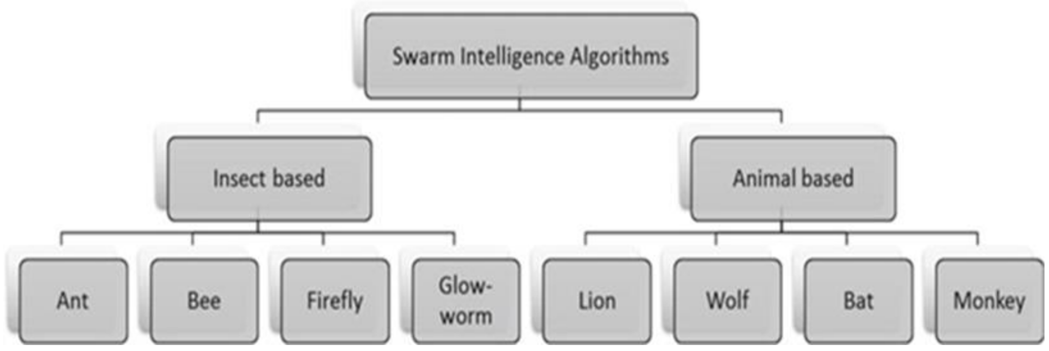

Figure 2.9: Swarm intelligence-based algorithms Hierarchy, as utilized in the present study[88].

In present work, we aim to offer an original met heuristic technique, that is, the Bat Algorithm, according to bats echolocation response, and initial investigations reveal that this algorithm is highly capable. The microbats' echolocation ability is interesting as bats could locate their prey and distinguish various insects kinds even in total darkness. A cutting-edge optimization algorithm is possibly naturally excited, usually fundamental, according to swarm intelligence. Plans for motivation are quite novel besides algorithms that could be of various kinds. Nevertheless, those kinds of algorithms are likely to use some exclusive features for expressing the primary enhancing methods. For instance, genetic algorithms had been stimulated utilizing Darwinian natural process characteristics methods, and genetic operators like mutation as well crossover, moreover, the choice of the most suitable utilized. Answers in hereditary algorithms are proposed as binary/real or chromosomes strings. Then again, PSO developed according to the swarming untamed birds also fish forms so that the multiagent device might have emergent residences of swarm or institute intelligence. Various PSO versions and developments are available in the literature, several sparkling modern metaheuristic algorithms have most genuinely been advanced[90].

Algorithms, for instance, PSO and genetic algorithms, might be quite appreciated, while they yet have some deadfalls in working with optimization difficulties of multimodal. One important improvement is the firefly algorithm (FA), which has been created entirely on the flashing features of tropic fireflies. The mild intensity coding, appeal conduct, and distance dependency give an unexpected ability to produce viable FA to do multimodal, nonlinear optimization problems accurately. Moreover, cuckoo search (CS) becomes created entirely on the brooding method of special cuckoo kinds that has been mixed with L´evy flights. The CS rules set is green only due to it has an excellent convergence run that could be shown the use of the Markovian chance method. Different approaches, such as the eagle approach are quite green. Because a revolutionary function, Ba rely on the echolocation common uses of microbats, and Bat rules set does use of the frequency-tuning technique to improve the treatments variety inside the populace, even though at using the automated zooming in attempting to balance also exploitation in time they are looking for a method with the help of imitating the variation of pulse emission fees and bats loudness even as attempting to locate the victim[93]. Thus, it appears to be highly efficient with a standard effective beginning. Surely, there might be a place for enhancement. Thus, this article would assess the latest developments in Ba.

2.3.1 Microbats Echolocation

Bats are interesting creatures. These mammals are the only ones with wings along with advanced echolocation ability. It is determined that around a thousand different kinds that represent approximately one-fifth of all mammal's kinds. Bats size varies from small as bumblebee bat (around a few grams) to large bats with a wingspan around two meters and weighs around one kg. Typically, microbats have distinctive style up to 11 cm forearm length. Most bats to a particular measure utilize echolocation; amid all kinds, microbats are a great example of utilizing echolocation greatly[94].

Most microbats are classified as insectivores. They employ a sort of sonar, named, echolocation, to discover food, evade barriers, as well as find their roosting holes in the dark. Those bats shoot very powerful sound oscillation and monitor for the echo that jumps off the neighboring things. Their oscillations differ in characteristics and could be associated with their pursuit approaches, dependent on the sorts. In general, most types of bats in nature or all over the world utilize short wavelength or frequency signals to carding around an octave.

In contrast, other kinds of bats have a different method of carding around an octave, Figure 2.10. These bats usually deal with echolocation by use constant-frequency signals. Kind of signal bandwidth depends on the type of bat and is usually augmented via applying additional harmonics [75].

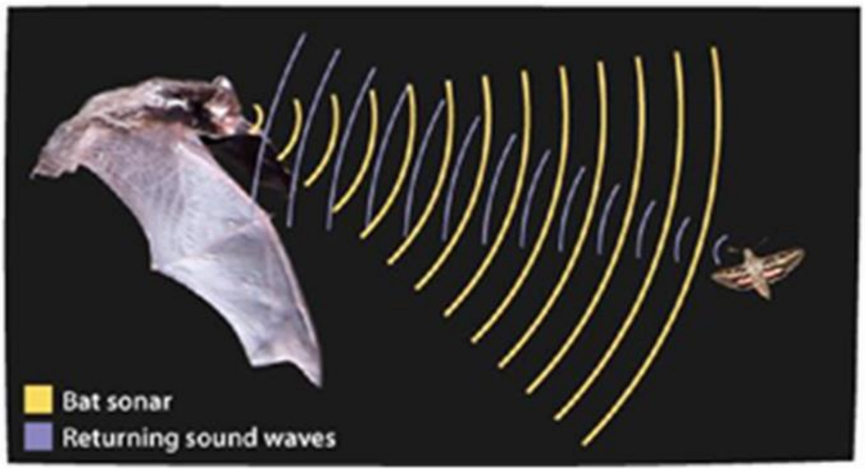

Figure 2.10: Bat echolocation[75].

However, every pulse just continues for a fracture of a second (up to around eight-ten ms); nevertheless, it has a fixed frequency that is normally in 25 to 150 kHz range, while most bat kinds frequencies are in the zone of 25 to 100 kHz; however, some types could release greater frequencies equal to 150 kHz. Every ultrasonic blast might usually continue five to twenty ms, and microbats release around ten to twenty such sound blasts each second. When chasing prey, the pulse emission rate could be promoted to around two hundred pulses per second when flying close to prey. Such small sound blasts specify the bats' incredible ability for signal processing power. Researches reveal the bat ear integration time is normally around three hundred to four hundred μs.

The speed of sound normally [$v = 340$ (m/s)] in the air, ultrasonic sound wavelength λ of blasts with fixed frequency f provided via [$\lambda = v/f$] with a specified range between two mm to fourteen mm for standard range 25 to 150 kHz frequency. Those wavelengths correspond to their food size.

Impressively, the released pulse is like 110 dB and luckily, in the ultrasonic domain. Noise is loud when looking for food and quiet when it comes to food. The travel range of such small pulses is usually several meters dependent on real frequency. Microbots can overcome small obstacles like human hair. Research has shown that the microbats delay the time between echo release and discovery, the time interval between their two ears, and the big change of resonance to create the surrounding 3D landscape. They can detect target range and orientation, bait type and speed of small insects. Research has shown that bats can penetrate targets through fluctuations in the Doppler effect due to the feather-pulsing movement of insects.

Apparently, some bats have an excellent vision, while most of them have a highly sensitive smell. In fact, they use a combination of every sense to enhance the effective search for hunting and elegant direction finding. Yet, we are concerned about echolocation and related conduct only.

Microbats Echolocation could be created in a way that combines the purpose of optimization, and it is possible to create unique algorithms for optimization. The following section will basically outline the Ba basic formulation and describes its application as well as comparison.

2.3.2 Bat Algorithm

If idealizing some echolocation features of microbats, we could make alterative bat-based algorithms. For understandability, we apply the next estimate rules:

1. All bats sense distance by employing echolocation, and they as well `know' the distinction between food/prey as well as obstacles in some magical process.
2. Bats fly arbitrarily to position xi at speed vi, a set frequency fmin, changing loudness A0 and wavelength λ to look for food. Bats could automatically modify the wavelength (or frequency) of the released pulses also modify the released pulse speed r in the [0, 1] range, based on the target closeness.
3. There are many ways to diversify loudness, but we propose that loudness can differ from great measure (+ A0) to least fixed value. Additional facilitation to note is that beam tracing cannot be used to determine time

lag and 3D landscape. Although this was a great characteristic when we used the method of computational geometry, it is better to utilize another feature because it is widespread in multi-dimensional problems.

Along with those simplified presumptions, we additionally employ the next estimates, for simplicity. Normally, the frequency f in $[f_{min}, f_{max}]$ range compatible with wavelength $[\lambda_{min}, \lambda_{max}]$ range. For instance, a frequency [20-500 kHz] range matches to 0.7 to 17 mm range wavelengths. For one problem, we could apply all kinds of wavelengths to make the implementation is easy. In real execution, the researchers could change any wavelength (or frequency coefficients), and the range of detectable must be selected, which is relative to the interest area size and harmonizing down to fewer ranges. Moreover, we do not certainly have to utilize the wavelengths themselves; rather, we could as well modify the level of acoustic frequency, whereas setting and preparing the wavelength λ. Which is due to f as well λ are correlated because of the fact of (λf) is steady. The researchers can utilize the same later way in their applications.

To make things easy, it is possible to suppose the value of f is between the period $[0, f_{max}]$. We understand that a high level of the frequencies propagate a smaller distance and have a short wavelength. For bats, the normal limits are several meters. The pulse rate could just be in the [0, 1] range, where zero indicates no pulses, and one indicates the pulse release at the maximum rate[91].

2.3.3 Virtual Bats Position and Velocity Vectors

In the simulation, we naturally use virtual bats and need to figure out how to update their speed vi and positions xi in the dimensional search zone. The velocities v_i^t and new solutions x_i^t at a step size of time t which are provided by the following relations:

$$f_{min} = f_{min} + (f_{max} - f_{min})\beta \quad (2.1)$$

$$v_i^t = v_i^{t-1} + (x_i^t - x_*)f_i \tag{2.2}$$

$$x_i^t = x_i^{t-1} + v_i^t \tag{2.3}$$

The random vector β could be obtained from a regular distribution of the domain. Where, $\beta\epsilon[0,1]$. The symbol x_* is selected as the best place or solution can be specified after studying all the solutions with n of bats. Because of $\lambda_i f_i$ refers to the speed increment, we could utilize one of them, either λ_i or (f_i) to modify the speed whereas we can choose the other factor λ_i or (f_i) according to the kind of concern problem. During this application, It is better to specify the value of f_{max} = 100 and f_{min} = 0 is dependent on the problem area size. Originally, every bat is specified the level of frequency randomly that can be selected equivalently of f_{min} and f_{max} . the new solution that can be selected among the best solutions for every bat is obtained locally utilizing the local walk randomly:

$$x_{new} = x_{old} + \varepsilon\, A^t \tag{2.4}$$

where ε is the random number, and $\varepsilon\ \epsilon\ [-1, 1]$

Therefore $A^t =< A_i^t >$ is the whole average of bats loudness.

It is necessary to update the bat's speeds and their positions after a specified time.

2.3.4 Alterations of pulsation Emission and Loudness

Moreover, the pulse rate r_i and the loudness A_i a release should be revived respectively and the iterations continue. As the loudness normally subsides as soon as a bat has located the victim, though it rises the rate of pulse emission, the loudness of voice should be determined for all convenience rates. As could utilize the value of $A_{min} = 1$ besides $A_0 = 100$. To make the problem easy, we could further utilize the value of $A_0 = 1\ beside\ of\ A_{min} = 0$ and this value of A_{min} refers to that the bat stops sending the sound because the bat discovered the victim.

$$A_i^{t+1} = \alpha A_i^t, \qquad r_i^{t+1} = r_i^0\ [1 - exp(-\gamma t)] \tag{2.5}$$

Where γ, as well as α, are constants. A is like schedule cooling factor in the simulated annealing, and the value is:

$$0 < \alpha > 1,\ \ 0 < \gamma\ ,$$

$$A_i^t \rightarrow 0,\ \ r_i^t \rightarrow r_i^0 \quad as\ \ t \rightarrow \infty \tag{2.6}$$

In the simple example, it is possible to apply the value of $\alpha = \gamma$, besides to utilize $\alpha = \gamma = 0.9$ in these models of simulations. There is a need to try to select the parameters. Originally, for each bat, there are distinct values. Every bat must have distinct values of frequency as well as loudness. For instance, the primary release rate r_i^0 could be close to zero while the value of primary loudness the primary loudness A_1^0 could usually be in the closed period [1, 2]. Their release rates, as well as loudness, will be refreshed only if the latest answers are perfected, and this means that the bats in the way for going into the best solution.

2.3.5 Bat Algorithm Applications

The conventional Ba, in addition to its numerous variations, indicating that the uses are actually distinct. Since the initial bat algorithm has been established, which it has been used in nearly every single in the field of optimization, data mining, classifications, processing of image, scheduling, selection of the feature, and many more. Next, we will shortly highlight some of the uses.

2.3.5.1 Continuous Optimization

Amid the first bat algorithm applications set, continuous optimization in the meaning of optimization engineering design is widely examined, which showed that Ba could handle very nonlinear problems effectively and could discover the best results precisely. Case studies involve designing the pressure vessel, truss systems and beam, design of the tower and the tall building, spring design in different shapes, car side design and many more. Tsai et al [95]. answered mathematical optimization difficulties utilizing bat algorithm. Furthermore, they optimized brushless DC wheel motors using Ba with greater outcomes. Ba could as well handle multi-objective problems effectively.

2.3.5.2 Combinatorial Optimization and Scheduling

From a computational difficulty perspective, continuous optimization could be rated as not that hard; however, it might be yet very demanding to answer. Nevertheless, combinatorial problems could be difficult, usually non-deterministic polynomial-time hard (NP-hard)[96] offered a comprehensive examination of combined emission dispatch and economic load difficulties utilizing Ba. They related bat algorithm along with hybrid genetic algorithm, ant colony algorithm (ABC) and other techniques, and they settled on Ba for being simple to execute and very preferred to be used rather than other algorithms due to precision and ability.

They solved different types of machine, multistage, multi problems of product scheduling using Ba, and they studied and solved the case of an NP-hard problem besides a complete parametric revision. They as well suggested that the implementation could increase by value around 8.4% by utilizing an optimum parameter set.

2.3.5.3 Parameter Estimation and Invers Problem

Apply Ba to microelectronic applications for analyzing topological shape optimization so that various elements thermal characteristics could be located and specified in a manner which made the transfer of the heat is effective in severe restraints. It is possible to use it for performing and estimating the parameter with an inverted issue. If an inverted issue could be correctly formed, then bat algorithm could give more reliable outcomes than regularization and least-squares methods.

2.3.5.4 Classifications, Clustering and Data Mining

Khan et al. [97] carried out a research on the problem of clustering and the office of workplaces utilizing a method of fuzzy Ba. Khan et al. [2012a] as well carried out comparative research of PSO with GA, BA, and different algorithms in e-learning case, and therefore recommended that BA has some benefits over different algorithms., Khan and Sahari further showed research and studies about problems of clustering by using a method of optimization Bat Algorithm and its expansion and they obtained great outcomes. They investigated K-means clustering utilizing Ba, and they assumed by combining Ba and K-means could deliver greater performance and therefore functions more reliable than different algorithms.

Furthermore, Mishra et al. utilized Ba to rank microarray data, whereas Natarajan et al. showed comparison research of cuckoo search and Ba for the optimization of Bloom filter. They investigated website phishing discovery using a modified bat algorithm and obtained satisfying outcomes. They applied Ba to investigate hybrid flow shop scheduling issues to reduce mean flow time and make span. Their outcomes implied that Ba is an effective method to determine hybrid flow shop scheduling issues. Also, they employed a modified Ba to record the cancellation of duplication as a method for data compression and optimization. The investigation proposes that altered Ba could achieve better results compared to the programming of genetic.

2.3.5.5 Image Processing

There are researches showed about human full-body posture estimate utilizing Ba by Abdel-Rahman et al. [98] They determined that Ba works well than PSO, PF, and APF. Additionally, they offered a different Ba with alteration for image matching and a designated new model of bat that is more efficient and possible in visualize equivalent compared to different copies like genetic algorithm.

2.3.5.6 Fuzzy Logic and Other Applications

Reddy et al. [75] carried out a research on optimal capacitor arrangement aimed at loss decrease in distribution systems by utilizing Ba with fuzzy logic to obtain the best sizes of a capacitor to reduce losses. The outcomes proposed that real power loss could be decreased considerably. Moreover, they utilized Ba and fuzzy systems for energy modeling and following many researchers and scientists like Hashim et al. [79] implemented Ba to investigate the systems of fuzzy to model the energy differences in gas turbines. At the same time of studying and writing different databases have been explored; we have obtained different documents on bat algorithms that both recently accepted or for conference demonstrations. Nevertheless, those documents do not have adequate information to be covered in this paper. As the literature is growing, more researches on Ba are being developed, and an additional timely review will be required in the following two years.

CHAPTER 3

The Governing Equations of Wave Propagation

Waves are an interesting physical phenomenon along with significant possible uses. Engineers and physicists are involved in the simulation methods in which waves are separated from barriers. The linear numerical models for scattering and wave propagation are known. Presume the performance of time-harmonic; one deals with the Helmholtz equation, where the physical parameter wave number is k. We are dealing with the basic relationships that refer to the physics of linear waves, such as elastic material waves, fluid-solid interaction, and acoustic waves. Therefore, we deal with two kinds of vectors on of them is a vector field (electrodynamics), and another is the scalar field (acoustics), both of those fields in the interface of fluid-solid, or bot of the are vector fields. Since waves are constant along with a circular frequency, a time-harmonic case must be of interest to us. Here we introduce that time variables are divided into time-dependent scalar fields, where is the static function. For relevant meeting vector fields[92].

3.1 Acoustic Waves

Sound waves are little pressure fluctuations in the compressed right fluid (sound medium). Those vibrations are combined to transmit energy to the medium. Rule equations are derived from the basic laws for compressed fluids.

3.1.1 Conservation of Mass

We assume fluid material flow with pressure $P(x,t)$ with specified velocity referred to it $v(X,t)$, Let us assume V is the volume component and has the boundary ∂V, and $n(x)$, $x\epsilon\, \partial V$, usual unit vector. The following relation mass conservation in the unit time period is stated as,

$$-\frac{\partial}{\partial t}\int_V \rho dV = \oiint_{\partial V} \rho(V.n)ds \tag{3.1}$$

The surface integral on the right side is converted to volume integral utilizing

$$\oiint_{\partial v} (\rho V).nds = \int_v div(\rho V)dV.$$

By using the Gauss theorem, we can obtain,

$$\int_v \left(\frac{\partial \rho}{\partial t} + div(\rho V) \right) dV = 0$$

That points into the continuity equation,

$$\frac{\partial \rho}{\partial t} + div(\rho v) = 0. \tag{3.2}$$

3.1.2 Equation of Motion

Assume the volume of the body is V subjected to a normal level of hydrostatic pressure $P(x,t)$. There are total force, expressed by the relation $-\oint PndS$, along to it by ∂V is then.

Where n means unit normal of the external vector along ∂V and the relation $F = ma$ is the second Newtonian law.

$$-\oiint_{\partial v} Pnds = \int_v \rho \frac{dV}{dt} dV$$

In general, the total different dV/dt is prolonged to the nonlinear expression.

$$\frac{dV}{dt} = \frac{\partial V}{\partial t} + (V.\nabla)V$$

With a small oscillation assumption, this relation is used in acoustic equations as linearized. Employing the time-harmonic hypothesis, which gets the expression of steady-state of the Euler equation,

$$i\omega\rho v = \nabla P$$

Where implement the variable separation as in the relation (3.1). We have defined that there are two kinds of vectors, vector field and scalar field. Including the fluid-particle displacement that expressed by the vector $u(x,t)$. The Euler equation is documented as the following:

$$\rho \frac{\partial^2 U}{\partial t^2} = -\nabla P \qquad (3.3)$$

Or, it can be expressed in the other form,

$$\rho\omega^2 u = \nabla p \qquad (3.4)$$

3.1.3 Wave Equation and Derive the Helmholtz Equation

The definition of acoustic wave by consider it as small perturbation(P, ρ) of steady state (P_0, ρ_0) of a perfect fluid. The point x, on the domain, there are two functions for hydrostatic pressure P(x,t) and mass density $\rho(x,t)$, express oscillations with a small level of amplitude. The speed of the Euler equation is small, and the law of linear material is ;

$P = c^2\rho$ (3.5)

Where the constant of the material c is named sound speed. Then, using linearized forms of (3.2), we get,

$P,_{tt} = c^2\rho,_{tt} = -c^2\rho_0 div\, V,_t = c^2 div(\nabla P)$

To attain the wave equation

$\Delta P - \frac{1}{c^2}P,_{tt} = 0$ (3.6)

Where $\Delta = \nabla.\nabla$ in spatial coordinates refers to the relation of Laplacian, with the assuming of time-harmonic waves, in conclusion, we get the Helmholtz equation.

$\Delta\, p - k^2 = 0$ (3.7)

With

$k := \frac{\omega}{c}.$ (3.8)

The physical parameter k of dimension expresses the wavenumber m^{-1} and we will explain this concept later.

3.1.4 Wave Equation of One Dimensional

Let us assume that $x \in R$. The solution of the wave equation in one dimensional is the following expression,

$P(x,t) = f(kx - \omega t)$

When $d(kx - \omega t) = 0$, The value of functions f does not include variation.

$\frac{dx}{dt} = \frac{\omega}{k}$ (3.9)

The expression,

$v_{ph} = \frac{dx}{dt}$ (3.10)

Is named the phase speed of the solution $f(kx - \omega t)$.

One-dimensional solution-phase velocity $f(kx - \omega t)$ is equivalent to sound speed in acoustic medium, and it reliant on $k \, or \, \omega$ is called nondispersive. The wavenumber k plays a major role in specifying the phase speed of dispersive waves.

3.2 Elastic Waves

Acoustic waves spread as small oscillation of the stress domain in an elastic medium. The dynamic elasticity equations are obtained from the same continuum mechanics basic relations as the hydrodynamic equations.

3.2.1 Elasticity Dynamic Equations

The components of stress tensor are $\sigma_{i,j}$ and the components of dynamic load F are in the case of equilibrium with the term $\rho_s U,_{tt}$ dynamic volume force components. U is the displacements vector.

$$\sigma_{ij,j} + F_i = \rho_s U_{i,tt} \tag{3.11}$$

For $i = 1,2,3$. Bear in mind collection convention must be employed on the left of the first term.

With assuming of little displacement, the strains relevant to displacement via linearized equations,

$$e_{ij=\frac{1}{2}(U_{i,j}+U_{j,i})}, \quad i,j=1,2,3 .$$

3.2.2 Material Law

The material is elastic :

$\sigma_{i,j}{=}\lambda e_{11}\delta_{ij}{+}2Ge_{ij}\,, \quad i,j{=}1{,}2{,}3,$ (3.13)

With

$\lambda = \frac{EV}{(1+V)(1-2V)} \quad , \quad G = \frac{E}{2(1+V)} \ ,$

Where V and E respectively, denote the solid Poisson ratio and Young's modulus, and collection convention applies for the term e_{ij}. The relation could express the expression of electrodynamic equilibrium:

$\Delta^{*}U + F = \rho_s U,_{tt}\ ,$ (3.14)

Where,

$\Delta^{*}U = G\Delta U + (\lambda + G)\nabla(\nabla . U).$ (3.15)

Where ΔU refers to the Laplacian vector,

$\Delta U = \{\Delta U_{1,}\Delta U_2, \Delta U_3\}^T$

$\nabla . U$ refers to the divergence of the vector field.

3.2.3 Vector Helmholtz Equations

There are additional changing in the Equation (3.15) and present the decomposition of the Helmholtz equation,

$U = \nabla\Phi + \nabla \times \Psi\ ,$ (3.16)

With two potentials, scalar $\Phi\ and\ vector\ \Psi$. This points to (in the volume forces absence),

$\nabla[\rho_s\Phi\Phi,_{tt} - (\lambda + 2G)\Delta\Phi] + \nabla \times [\rho_s\Psi,_{tt} - G\Delta\Psi] = 0,$

Which is fulfilled if wave equations,

$\Phi,_{tt} - \alpha^2\Delta\Phi = 0\ ,$ (3.17)

$$\Psi_{,tt} - \beta^2 \Delta\Psi = 0\ , \tag{3.18}$$

The sound elastic speeds are known by ,

$$\alpha = \left(\frac{\lambda+2G}{\rho_s}\right)^{1/2}\ ,\ \beta = \left(\frac{G}{\rho_s}\right)^{1/2}$$

Then G = 0, the equation (3.17) lessens to the equation of sound wave. As

$$\lambda = B - 2/3G\ ,$$

The symbol B is the modulus of material bulk, and the sound speed in the acoustic medium is,

$$c = \sqrt{\frac{B}{\rho}} \tag{3.19}$$

All waves in the sound medium are compressed. Along with the compression waves, and there are more shear waves in an elastic medium.

With the fields of time-harmonic presumption, the equations of elastic wave point to Helmholtz equations.

$$\Delta\Phi + k_\alpha^2 \Phi = 0\ , \tag{3.20}$$

$$\Delta\Psi + k_\beta^2 \Psi = 0\ , \tag{3.21}$$

$$k_\alpha := \frac{\omega}{\alpha}\ , \qquad k_\beta := \frac{\omega}{\beta}.$$

3.3 Acoustic / Elastic Fluid – Solid Interaction

Acoustic waves are shown from the right lane. This is called the right sound scattering. When the barrier is elastic, a portion of the external incident force is spread in the shape of oscillations. Many of acoustic plan waves work as various time loads, making mandatory oscillations. In that case, we are talking about a decent spread. On the other hand, when the acoustic medium receives physical activity embedded in the body of the acoustic wave. We contemplate elastic scattering making these presumptions.

Let $\Omega \subset R^3$ be the restricted domain of solid along with boundary Γ (named wet surface) that is surrounded via means of the boundless fluid domain $\Omega^+ = R^3 \backslash \Omega$. It is presumed outbound waves are absorbed in a distant field. The waves do not resonate from infinity.

The fluid assumed homogeneous and perfect compressible with density and sound speed. The solid barrier is regarded as stiff or linear flexible with density. The fluid has a scalar pressure field indicated via hydrostatic pressure. The solid displacements vector field is indicated via U(x,t). All types of acoustic waves such as longitudinal and shear waves are in case of steady-state along with all digress of circular frequency and providing the suitable separation. In the liquid domain, an incident sound field is provided, and the solid domain is subject under the harmonic waves and driving force,

$F(x,t) = F(x)\exp(-i\omega t)$

The system of the Cartesian coordinate is set, and the goal is to define the field of the constant sound of hydrostatic scattered pressure P (x). The answer is complicated. Physical interest is the answer before the actual part.

$P(x,t) = P(x)e^{-i\omega t}$.

We have,

$Re\ P = Re((Re\ p + i\ Imp)(cos\ cos\ \omega t - i\ \ sin\ sin\ \omega t))$

Where we define $\phi \coloneqq arctan\ \frac{Rep}{Im\ p}$,

Therefore, in the typical nomenclature for harmonic motion, the stationary solution absolute value is the physical solution amplitude, while ϕ is the phase.

3.4 Analytic Development

In this section, energy transmitted and reflected in the cylinder is derived in the form of a mathematical equation. The concerns in this chapter consider a circular, cylinder defined in cylindrical polar coordinates [77]. The duct wall has a rigid structure, resulting in a symmetrical axis framework. The θ coordinate is then dropped. The interior field includes a compressible sound level fluid c and density ρ. A harmonic time factor, $e^{-i\omega t}$ range, is assumed whenever t is time and range = ck, where k is the wavenumber of fluids. The Helmholtz equation shall give the governing equation for the interior area,

$$\left\{\frac{\Delta^2}{\Delta \bar{r}^2}+\frac{1}{r}\frac{\Delta}{\Delta \bar{r}}+\frac{\Delta^2}{\Delta \bar{z}^2}+k^2\right\}\bar{\phi}=0 \tag{3.22}$$

Where the dimensional velocity potential of the fluid is $\bar{\phi}$. This velocity potential is a scalar function that had a gradient equal to the fluid velocity [78]. This can be used to describe future potential, such as:

$$\bar{p}=i\omega\rho\bar{\phi} \tag{3.23}$$

Where the aspect pressure is $\bar{p}$. As standard time and length scales, it is useful to non-dimensionalize the dimensional variables with respect to both ω^{-1} and k^{-1}. In terms of their non-dimensional counterparts, the dimensional variables are then

$$k\bar{r}=r, k\bar{z}=z, k^2\bar{\phi}=\omega\phi \tag{3.24}$$

Consequently the non-dimensionalized governing equation is

$$\left\{\frac{\Delta^2}{\Delta r^2}+\frac{1}{r}\frac{\Delta}{\Delta r}+\frac{\Delta^2}{\Delta z^2}+1\right\}\bar{\phi}=0 \tag{3.25}$$

Where ϕ is the potential of non-dimensional fluid velocity. The method of separating variables is used to evaluate the velocity potential, which depends on r and z and thus takes the form

$$\phi=R(r)Z(z) \tag{3.26}$$

The ϕ is substitute in the equation (3.25), finally we get,

$$\frac{1}{R}\frac{\Delta^2 R}{\Delta r^2} + \frac{1}{rR}\frac{\Delta R}{\Delta r} + 1 = -\frac{1}{Z}\frac{\Delta^2 Z}{\Delta z^2} \quad (3.27)$$

The right side of the equation (6) is considered as negative separation constant, and it will oscillate in the z-direction, and it considers as,

$$-\frac{1}{Z}\frac{\Delta^2 Z}{\Delta z^2} = S^2 \quad (3.28)$$

The 'S' is the separation constant and expressed by the Euler's formula as,

$$Z(z) = Ce^{isz} + De^{-isz} \quad (3.29)$$

Where C and D are considered as an arbitrary constant. When considering, C=1 and D=0 then the wave propagating only in a positive direction and equation become [79],

$$Z(z) = Ce^{isz} \quad (3.30)$$

The Z(z) is substituted in the equation (6) and equation become,

$$r^2\frac{\Delta^2 R}{\Delta r^2} + r\frac{\Delta R}{\Delta r} + r^2(1 - S^2)R = 0 \quad (3.31)$$

The expression above is known as the differential equation of Bessel and the velocity potential can be expressed by,

$$\phi_n = \sum_0^\infty A_n J_0(k_n r)e^{is_n z} \quad (3.32)$$

Where A_n and S_n are the amplitude of the n^{th} wave and wavenumber.

A terminology for the energy propagating through a cylinder is necessary to determine whether the energy is reflected and/or travelled at a discontinuity [80]. Because the cylinder cannot hold energy, it only considers the energy in the fluid.

The dimensional power is generated by the integration of the pressure compounded by the dynamic conjugation of the velocity over the cross-section is given by,

$$\varepsilon = real\left[\int_0^a i\phi\left(\frac{\Delta\phi}{\Delta z}\right)^* r\Delta r\right] \tag{3.33}$$

On substituting velocity potential (11) into (12), we get,

$$\varepsilon_n = real\left[\int_0^a iA_n J_0(k_n r)e^{is_n z}\left\{is_n A_n J_0(k_n r)e^{is_n z}\right\}^* r\Delta r\right] \tag{3.34}$$

It can be expressed as follows,

$$\varepsilon_n = real\left[s_n |A_n|^2 \int_0^a J_0^2(k_n r) r\Delta r\right] \tag{3.35}$$

From the equation (14), we write wave scattering energy and travelled energy as follows,

$$\varepsilon_A = real\left[\sum_{m=0}^{M} |A_m|^2 s_m C_m\right] \tag{3.36}$$

$$\varepsilon_B = real\left[\sum_{m=0}^{M} |B_m|^2 \eta_m D_m\right] \tag{3.37}$$

Where A_m is the amplitude of the scattered wave, and B_m is the amplitude of the travelled wave, S_m and η_m are the wavenumbers of the scatter and travelled wave. C_m and D_m are given by the following equation,

$$C_m = \frac{a^2 J_0^2(k_m a)}{2} \tag{3.38}$$

$$D_m = \frac{b^2 J_0^2(\gamma_m b)}{2} \tag{3.39}$$

Where “a” is the radius of the outer cylinder, “b” is the radius of the inner cylinder, k_m and γ_m are given by,

$$k_m = (1 - S_m^2)^{(1/2)} \tag{3.40}$$

$$\gamma_m = (1 - \eta_m^2)^{(1/2)} \tag{3.41}$$

While considering the thickness “h” of the cloaking material and the characteristic equation of the wave motion in the cylinder as follows,

$$\frac{\nu}{\bar{a}}\frac{\Delta\bar{u}}{\Delta\bar{z}}+\frac{1}{\bar{a}^2}\frac{\Delta\bar{v}}{\Delta\theta}+\frac{\bar{\omega}}{\bar{a}^2}+\frac{h^2}{12}\frac{\Delta^4\bar{\omega}}{\Delta\bar{z}^4}+\frac{2h^2}{12\bar{a}^2}\frac{\Delta^4\bar{\omega}}{\Delta\bar{z}^2\Delta\theta^2}+\frac{h^2}{12\bar{a}^4}\frac{\Delta^4\bar{\omega}}{\Delta\theta^4}-\frac{\omega^2\bar{\omega}}{c_s^2}-\frac{\bar{p}(\bar{a},\bar{z})}{c_s^2\rho_s h}=0,\bar{r}=\bar{a}\quad(3.42)$$

Longitudinal, circumferential and radial cloaking material displacements are denoted by $\bar{u},\bar{v}\, and\, \bar{w}$. Poisson ratio is denoted “υ”, the sound speed of the cloaking material “c_s” is given by the following equation,

$$c_s=\sqrt{\frac{E}{(1-\upsilon^2)\rho_s}}\quad(3.43)$$

Where “E” is the young’s modulus and ρs is the density of the cloaking material [81]. From the equation (3.21) is noted that the reflected energy equation is depended on three variable such as a thickness of the cloaking material (h), Poisson ratio (υ) and density of the cloaking material (ρs). in this thesis, this will consider as optimize parameter to reduce the scatter effect in the cylinder and gain value of the equation (3.15) consider as the fitness function of the optimization problem, and it is given as,

$$Fitness=20*\log(\varepsilon_A)\,db\quad(3.44)$$

The thickness, density, and Poisson ratio are optimized using the Bat algorithm. The basic of the Bat algorithm is explained in the next section.
The Bat algorithm takes advantage of Bats 'echolocation activity. Such Bats emit a very loud sound pulse (echolocation) and listen to the echo that echoes back from the objects around them. Their amplitude of the signals varies according to nature. Each sound signal has an emission rate of pitch, loudness, and duration. Some Bats use tuning frequency signals while the majority use fixed frequency signals. Such animals have a frequency range of between 25 kHz and 150 kHz. Bat algorithms are based on the following aspects; both Bats use echolocation, and the distinction between victim and obstacle is separated. Bats travel at a random speed, at a

random venue, with variable length, loudness, and pulse emission rate [82][83]. The flowchart for the Bat algorithm is shown in Figure 3.1.

Step 1:

Initialize the Bat position Xi=X1, X2, X3…Xd, initialize the Bat velocity Vi=V1, V2, V3…Vd. Where d is the number of optimized parameters of the system. The next process to find out the objective function value (F(i)) for the initial Bat position (Xi), i.e.,

$$X(i) = rand(n, d); n\ is\ the\ number\ BAT\ population \tag{3.45}$$

$$V(i) = rand(n, d); n\ is\ the\ number\ BAT\ population \tag{3.46}$$

$$F(i) = f(X(i)) \tag{3.47}$$

After finding the objective function value, store the result and corresponding Bat positions for further manipulation of the Bat algorithm.

Step 2:

Define values for the pulse frequency of the Bats (Q_i), Pulse rate of the Bats (r_i) and loudness factor of the Bats (A_i).

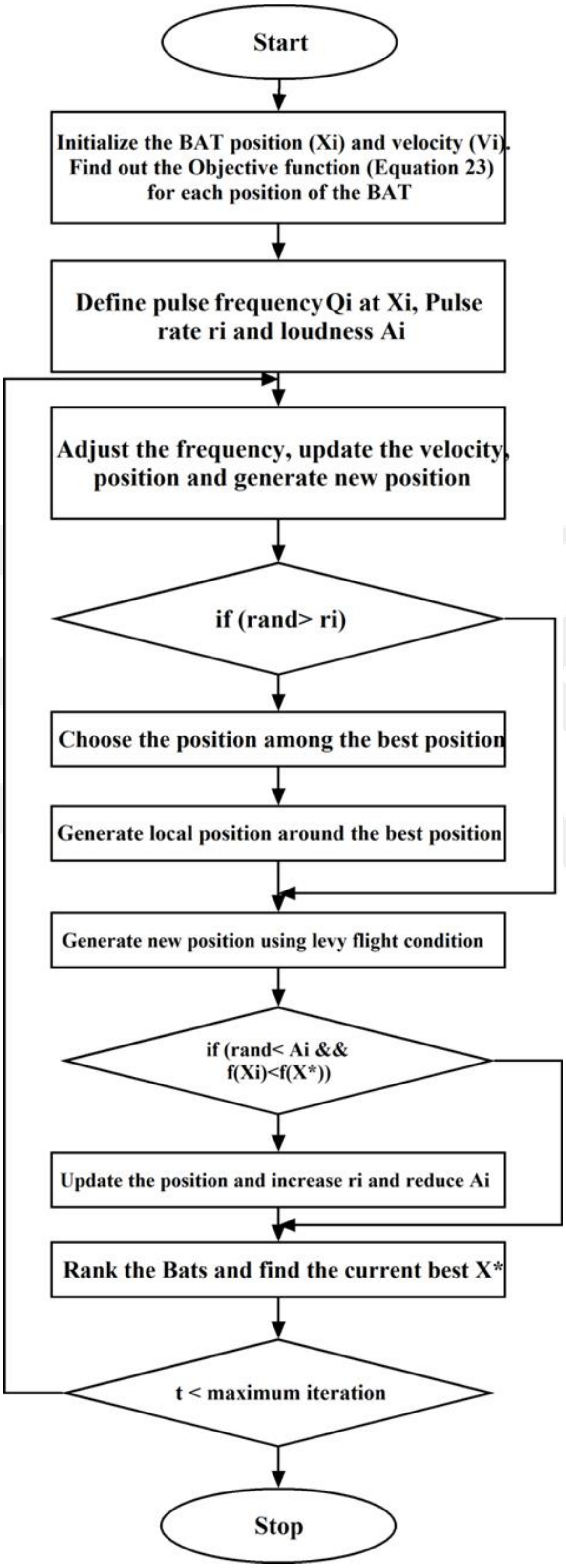

Figure 3.1: Flowchart for the Bat algorithm

Step 3:

Bat algorithm's main loop starts at step 3. In this loop, the iteration count is set as 1. Maximum iteration for the main loop fixed here.

Step 4:

Adjust the frequency parameter of the Bats using minimum and maximum frequency value and given by the following equation,

$$Q_i = Q_{min} + (Q_{max} - Q_{min}) * rand(n, d) \quad (3.48)$$

Where Q_{min} is the minimum frequency of the Bat, Q_{max} is the maximum frequency of the Bat, and rand (n,d) is the rand number between zero to one.

Update the velocity of the Bat using the best position and frequency of the Bat positions. It is given in the following equation,

$$V(t) = V(t-1) + (X(t-1) - X^*)Q_i \quad (3.49)$$

Where, V(t) is the current iteration velocity, V(t-1) is the previous iteration velocity, X(t-1) is the previous iteration Bat positions, X^* is the best position among all Bat position and Q_i is the frequency of the Bats.

Update the position of the Bats using an updated velocity of the Bats, and it is described by using the following equation,

$$X(t) = X(t-1) + V(t) \quad (3.50)$$

The best position for the Bat is derived from the old position added with loudness factor of the Bats, and it is expressed in the following equation,

$$X(new) = X(t) + rand * A_i(t) \quad (3.51)$$

Step 5:

In the step, the pulse rate of the Bats is compared with a random pulse rate. If the pulse rate less than the random pulse rate, then choose a solution among the best solution to the problem and also create the local solution around the best solution selected. After that update the pulse rate and loudness factor of the Bats using the following equations,

$$\mathrm{r_i(t)} = \delta * r_i(t-1),\ \mathrm{A_i(t)} = \mathrm{A_i^0}\left(1 - e^{(-\emptyset t)}\right) \tag{3.52}$$

Where δ and $\emptyset$ are random numbers.

For considering the values for δ and $\emptyset$ $0 < \delta < 1$ and $\emptyset > 0$, and consider iteration reach infinite then pulse rate and loudness factor becomes,

$$\mathrm{t} \to \infty, \mathrm{r_i}(\infty) \to 0,\ \mathrm{A_i}(\infty) = \mathrm{A_i^0}\ \mathrm{as} \tag{3.53}$$

Create a new solution using levy flight conditions in this step.

Step 6:

If (rand < A_i & F (Xi) < F(X*))

In this step, compare the loudness factor with a random loudness factor and also compare the current solution with the best solution if both conditions are satisfied, then increase the pulse rate of the Bats and reduce the loudness factor of the Bats as in the equation (3.51).

End if

Sort the Bat's solution and determine the current best solution X*.

End while

Loop end

Step 7:

Display the best results from the Bat algorithm.

3.5 Method of Bat Algorithm

Bat algorithm (BA) is a meta-heuristic optimization algorithm, and it was done by Xin-She Yang in 2010 to be one of the best optimization algorithms [84]. In original Ba, the effect of Doppler and the foraging idea of the Bat were not considered, and each essential Bat is expressed by position and velocity, and it searches preys during dimensional spaces with achieving trajectory. Actually, this case does not exist only. In the BA, the Doppler Effect is included and an essential Bat can recompense adaptively for the Doppler Effect in the phenomenon of echoes [85][86].

The essential Bat is viewed to possess foraging habitats diversely in the BA. Bat searches for its food solely in one habitat in Ba because of the mechanical conduct of the virtual Bat. In summary, the Ba is obligated for the following idealized basics:

1. The motion of Bats can be around in various habitats.
2. Bats can recompense for the effect of Doppler in the echo phenomenon.
3. Bats can acclimate and set their compensation averages, and they depend on its target proximity.

3.5.1 Quantum Behavior

It is supposed that Bat s are going to conduct in such a behavior that while one of the Bat's group found its prey in a specific habitat, immediately the rest Bats would start to feed on the same prey. This supposition guides mathematically to the following formulation of the Bat positions [86].

$$X_{i,j}^{t+1} = \begin{cases} g_j^t + \theta * \left| mean_j^t - X_{i,j}^t \right| * \ln(\frac{1}{u_{i,j}}), if rand_j(0,1) \langle 0.5 \\ g_j^t - \theta * \left| mean_j^t - X_{i,j}^t \right| * \ln(\frac{1}{u_{i,j}}), if rand_j(0,1) \langle 0.5 \end{cases} \quad (3.54)$$

3.5.2 Mechanical Behavior

It is supposed that the speed of the virtual Bat will not overtake the sound speed, which is estimated 340 m/s. The Bat will compensate the Doppler Effect, and this compensation will be expressed mathematically as CR that it varies among various Bats. CR and the inertia weight (w) are in the range of 0 to 1. The value (ξ) represents the smallest constant to avoid the probability of division by 0. CR will be 0 if there is no compensation for the Doppler Effect by the Bat, and it will be 1 if there is compensation. This description can be expressed mathematically as follows:

$$f_{i,j} = fminmax_{min} \tag{3.55}$$

$$f_{i,j} = \frac{c+v_{i,j}^{t}}{c+v_{g,j}^{t}} * f_{i,j} * (1 + CR_i * \frac{g_j^t - X_{i,j}^t}{\left|g_j^t - X_{i,j}^t\right| + \xi}) \tag{3.56}$$

$$V_{i,j}^{t+1} = w * V_{i,j}^{t} + (g_j^t - X_{i,j}^t) * f_{i,j} \tag{3.57}$$

$$X_{i,j}^{t+1} = X_{i,j}^{t} + V_{i,j}^{t} \tag{3.58}$$

3.5.3 Local Search

It is supposed logically that Bats will raise the value of the pulse emission rate and reduce loudness when they approach prey. Whatever loudness value Bats use, the loudness factor needs to be considered in around the environment. This description means, the equations have been developed and expressed as follows:

If (rand (0, 1) > ri)

$$X_{i,j}^{t+1} = g_j^t * (1 + randn(0, \sigma^2)) \tag{3.59}$$

$$\sigma^2 = |A_i^t - A_{mean}^t| + \xi \tag{3.60}$$

Where rand n $(0, \sigma^2)$ as Gaussian distribution with mean value 0, and (σ^2) is the standard perversion, and (A^t_{mean}) is the mean loudness.

In our study, we used the Bat Algorithm (BA) [87] to determine the characteristics of a bi-layer material to minimizing the scattering. The parameters of the Bat Algorithm are shown in Table 3.1:

Table 3.1: The Parameters of Bat Algorithm.

Parameter	Description	Value
M	Maximum generations (iterations)	1000
Pop	Population size	30
Dim	Dimension	(0.1)
$r0_{max}$	Maximum pulse rate	1
$R0_{min}$	Minimum pulse rate	0
A_{max}	Maximum loudness	2
A_{min}	Minimum loudness	1
Freq D_{max}	Maximum frequency	1.5
Freq D_{min}	Minimum frequency	0
G	The frequency of updating the loudness and pulse emission rate	10
Prop $_{max}$	Maximum probability of habitat selection	0.90
Prop $_{min}$	Minimum probability of habitat selection	0.7
$Theta_{max}$	Maximum contraction-expansion coefficient	1
$Theta_{min}$	Minimum Contraction-expansion coefficient	0.5
C_{max}	Maximum compensation rate for Doppler effect in echoes	0.8
C_{min}	Minimum compensation rate for Doppler effect in	0.1

Parameter	Description	Value
	echoes	
w_{max}	Maximum inertia weight	0.80
w_{min}	Minimum inertia weight	0.50

The main steps of the BA can be expressed as a pseudo-code as follows:

Input: N: the number of individuals (Bats) contained by the population.

Step 1: Define the parameters.

If (rand (0.1) < P)

Step 2: Generate new solutions using equation (1).

Else

Step 3: Using equations (2)-(5). Generate new solutions.

End if.

If (rand (0.1) > ri)

Step 4: Using equations (6) and (7) generate a local solution around the selected best solution.

End if

Step 5: Evaluate the value of the objective function for each individual.

Step 6: Using equations of original BA, Update the solutions, the pulse emission rate and the loudness.

Step 7: Rank the solutions and find the current best (gt).

If (gt) does not improve in G time step,

Step 8: Re-initialize the loudness (Ai), and set temporary pulse rates (ri), which is a uniform random number between [0.85- 0.9].

End if

t = t + 1;

End while

Outputs: the output represents the individual with the values of the fuel cost function in the population.

The flow chart of BA is shown in Figure 3.2.

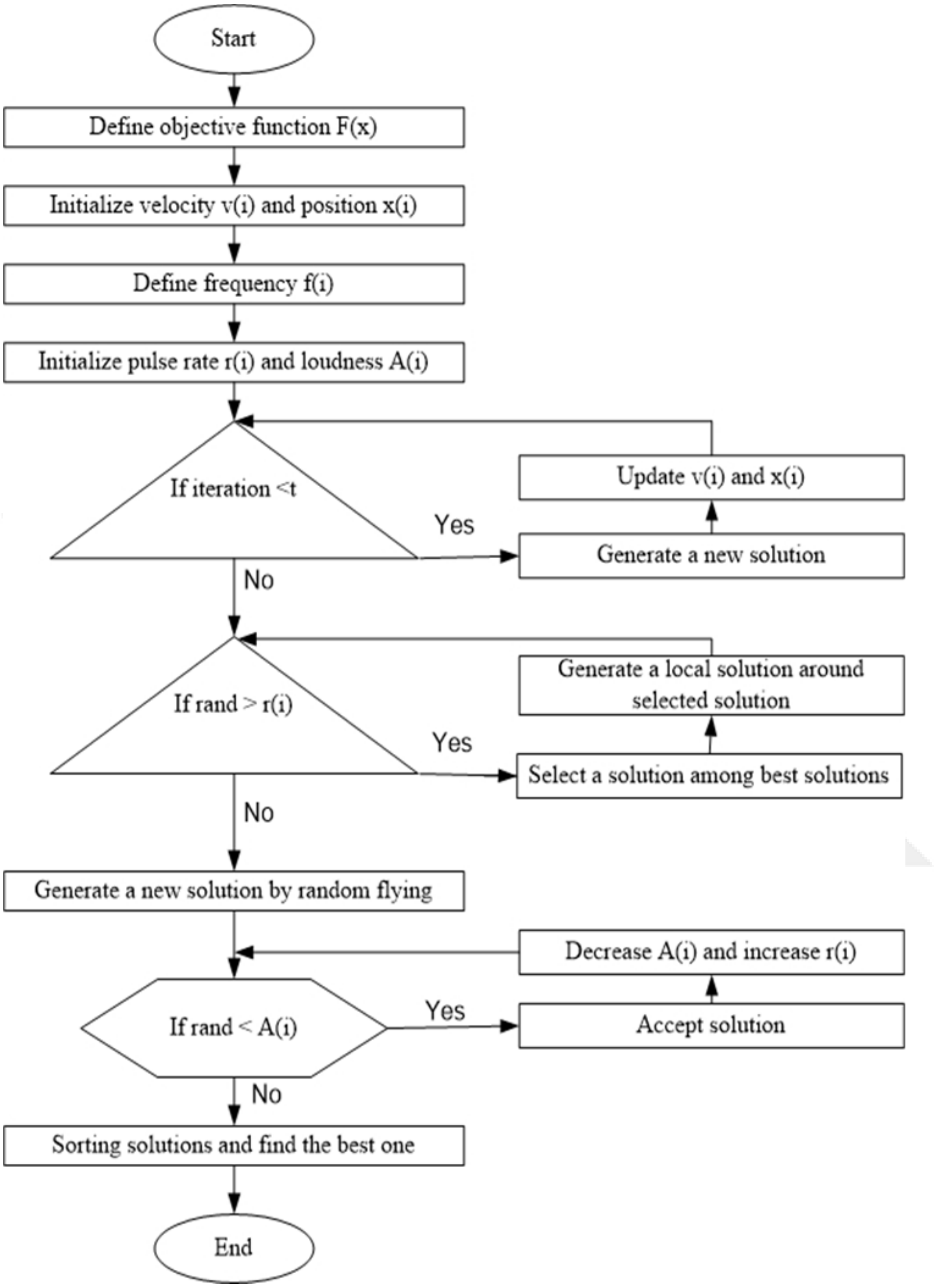

Figure 3.2: Flowchart of BA

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CHAPTER 4

Experimental Results

In order to verify the scattering reduction behavior in the cylinder object, MATLAB software was used to create the program to measure and analyze the reflected energy of the acoustics wave in the cylinder with cloaking and without cloaking conditions. MATLAB 2017b version used for simulation in the i3 Intel processor having 1.7GHz speed personal computer. For the elastic layers, optimization techniques were used to identify dimensional and mechanical characteristics that lead to a reduction in scattering. For cloaking layer, those parameters which constitute the variables of optimization are:

1. The thickness (h) of the cloaking material
2. Poisson's ratio (υ) of the cloaking material
3. The mass density (ρ_s) of the cloaking material

The parameter used for the acoustics wave analysis in the cylinder is given in Table 4.1.

Table 4.1: Parameter used for the acoustics wave analysis in the cylinder.

S.NO	Description	Value	Unit
1	Dimensional radius of the cylinder (a)	0.2	Meter
2	Dimensional radius outer layer of the cylinder (b)	0.28	Meter
3	Sound speed of fluid	343.5	m/s
4	Density of fluid	1.2	(kg/m^3)
5	Young's Modulus	7.2×10^{10}	(N/m^2)
7	Dimensional cloaking material thickness	To be optimized	Meter
8	Density of cloaking material	To be optimized	(kg/m^3)
9	Poisson ratio of cloaking material	To be optimized	-

The response of the scattering gain of the without cloaking material with different frequencies is shown in Figure 4.1. From this analysis, it is shown that the scattering gain is high with a different frequency of the acoustics wave and needs cloaking action to reduce the scattering gain of the acoustic wave through the cylinder.

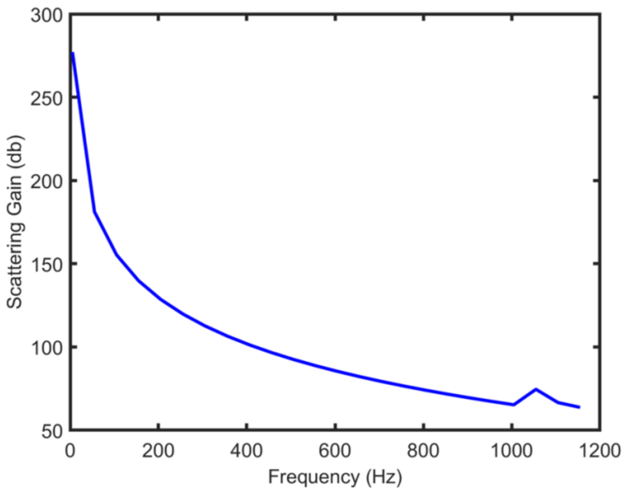


Figure 4.1: Scattering gain for the without cloaking material.

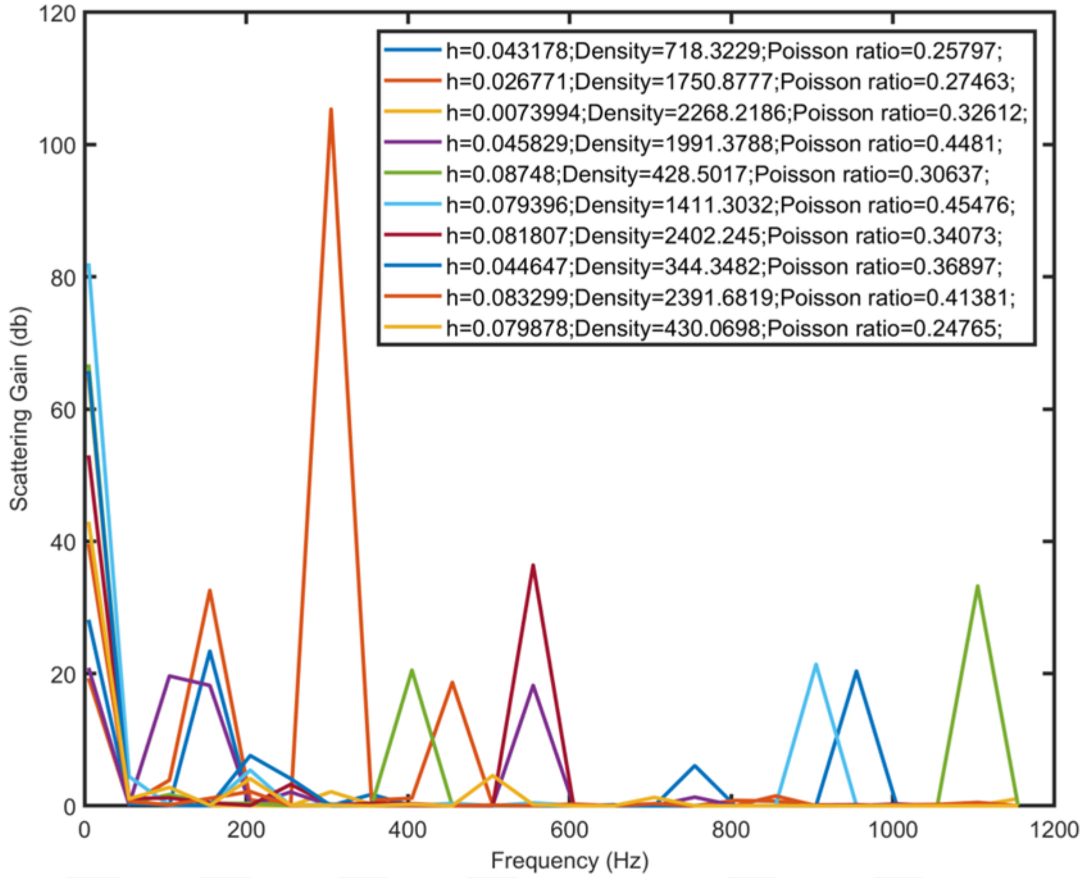


Figure 4.2: Scattering gain with random value of thickness, density and the Poisson ratio of the cloaking material.

Initially, ten random numbers were assigned for cloaking material thickness, cloaking material density, and cloaking material Poisson ratio and corresponding scattering gain value is measured with respect to acoustic wave frequency variation from 1 Hz to 1200 Hz. The result of this analysis is shown in Figure 4.2. From this analysis, it is showing that scattering gain values are zero in some acoustic frequency, and it has high value for some other frequency. So random optimization not possible to find out the optimal values for the given objective problem. For that purpose, the Bat algorithm used here to find out the optimal value for the cloaking material thickness, density, and Poisson ratio. The parameter used for the Bat algorithm is shown in Table 4.2.

Table 4.2: Parameter of the Bat algorithm.

S.NO	Description	Parameter of the Bat algorithm	
1	Generation	t	100
2	Population size	n	20
3	Number of parameters	d	3
4	Random number	δ and $\emptyset$	0.9
5	Pulse rate	r	0.5
6	Loudness Factor	A^0	0.5
7	Minimum Frequency	Q_{min}	0
8	Maximum Frequency	Q_{max}	2

The Bat algorithm executed with t=100 generation, n=20 population, and TR=1000 trial, then Bat algorithm finds the 2000000 solutions ($S = t \times n \times TR = 2000000$) for 1000 trials. Each trial's results are stored and analyzed in detail.

Table 4.3: Result of the Bat algorithm optimization.

Thickness	Density	Poisson ratio	Best Fitness	Worst Fitness	Mean	Standard Deviation	Computation time (min)
0.0935	2827.1463	0.425	0.43273	0.542	0.4623	0.0615	32.2

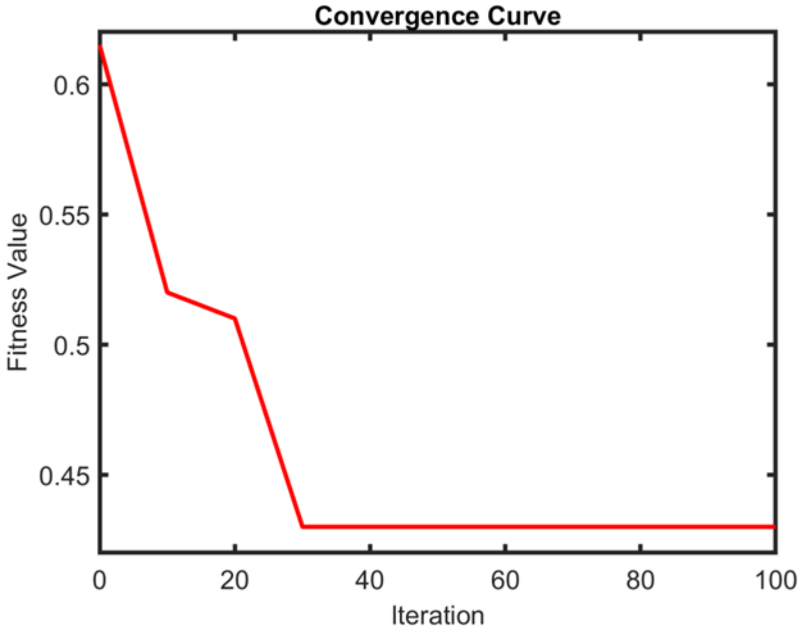


Figure 4.3: Convergence curve of the Bat algorithm.

The results from the Bat algorithm are shown in Table 4.3. The convergence graph for the Bat algorithm optimization is shown in Figure 4.3. Table 4.3 shows the optimal value of thickness, density, and the Poisson ratio of the cloaking material. The time required for a single trail is 30 minutes. The best fitness value, worst fitness value, mean value, and standard deviation for the 1000 trails are also presented in Table 4.3. From the convergence graph, the fitness value is minimized every iteration, and global value reached after 25 iterations.

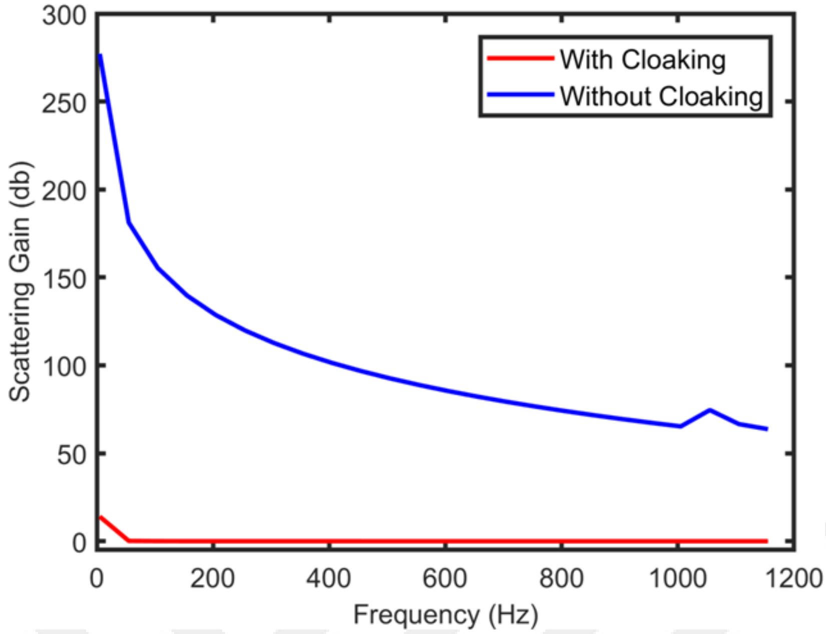
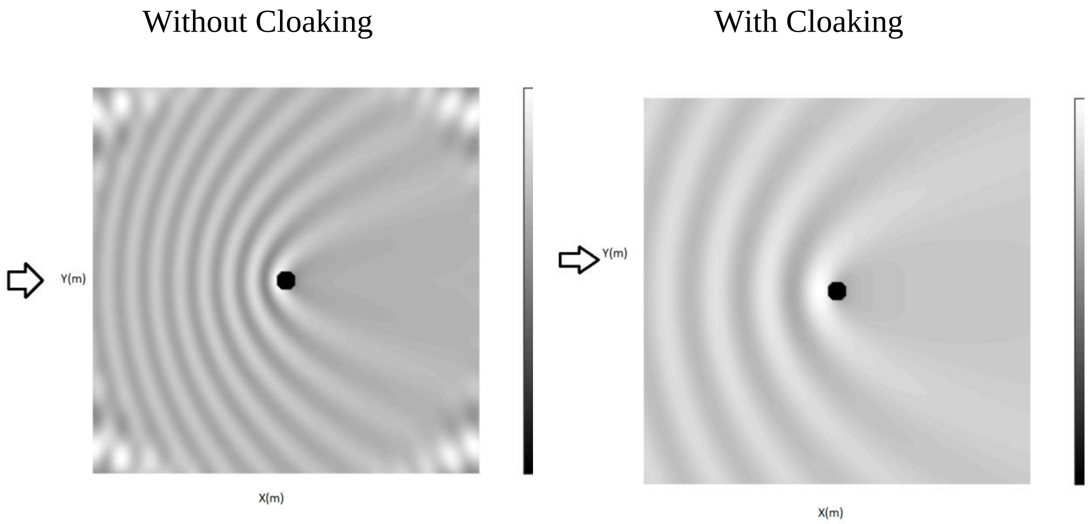


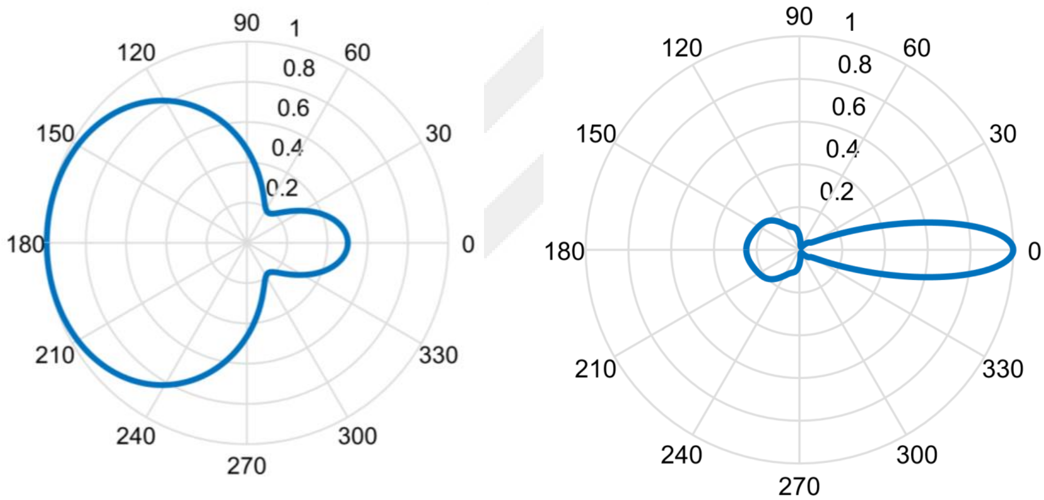
Figure 4.4: The graph of scattering gain (dB) vs. frequency.

The system is tested with optimized values, and corresponding results are measured and analyzed. The variation of the scattering gain with respect to frequency for without cloaking and with cloaking is shown in Figure 4.4. From this figure, It is shown that the scattering gain value is reduced when using cloaking material around the cylinder than the without cloaking around the cylinder.

Figure 4.5 (a) shows the sound pressure field in the cloaked cylinder and without a cloaked cylinder. The pressure around the shrouded cylinder ranges between 0.9 and 1.1 Pa with an incident plane wave with amplitude p0= one Pascal, particularly in the abrupt proximity of the cloaked cylinder anywhere it is concentrated around 1.1 Pa to 1.2 Pa. Association with the rigid cylinder condition, in which the pressure field took values around 0.4 and 1.8 Pa, indicates the tool output at this level. The cloaked cylinder's "averaged visibility," as described in [28] for characterizing the cloaking efficiency, is about 0.04 near the cylinder and 0.1 everywhere else.



(a) Pressure field in the rigid cylinder



(b) Scattered pressure in directive patterns

Figure 4.5: (a) Pressure field in the rigid cylinder, (b) Scattered pressure in the directive patterns.

From the directivity patterns of scatter pressure analysis shown in Figure 4.5(b), it is observed that reduction in scattering pressure in the cloaked cylinder than without cloaked cylinder. Using this cloaking material reduces the distant field diffraction in the direction of 180°, i.e., to the side of the wave of the event. Diffraction at the back of the cylinder is also high, for angles around 45° and 75° and 305° and 335°. The reduction of scattering gain is important in all directions: change in the amplitude of the diffracted pressure falls from the average value of one when considering without cloaking to the amplitude smaller than 0.1 with cloaking.

For the elastic layers, optimization techniques were used to identify dimensional and mechanical characteristics that lead to a reduction in scattering.

For each layer, those parameters which constitute the variables of optimization are:

1. the thickness h,
2. Young's moduli in the different directions E_r, E_θ, E_z,
3. the shear modulus $G_{r\theta}$,
4. Poisson's ratio $\nu_{r\theta}$, $\nu_{\theta z}$ and ν_{rz},
5. the mass density ρ,
6. the structural loss factor η.

In this thesis, the parameter used is shown in Table 4.4.

Table 4.4: Initialization values.

Parameter	Value
Speed of sound	340
Highest frequency for predictions	8000
Point source position	x0 = -2.5, y0 = 4, z0 = -1
Receiver position	x = 4, y = 3, z = 1
Panel is 2a long in x-direction	0.7
Panel is 2b long in z-direction	1
Half depth of panel corrugation (set d=0 to get plane surface)	0.1

The sampling frequency used is this number times the highest frequency of interest. Typically it's greater than 10. The element size used for the surface discretization is lambda/this number calculate the surface reflection using a time-domain Kirchhoff model.

Modeling the reflection from a rigid surface using a time-domain equivalent of the Kirchhoff solution is shown in Figure 4.6.

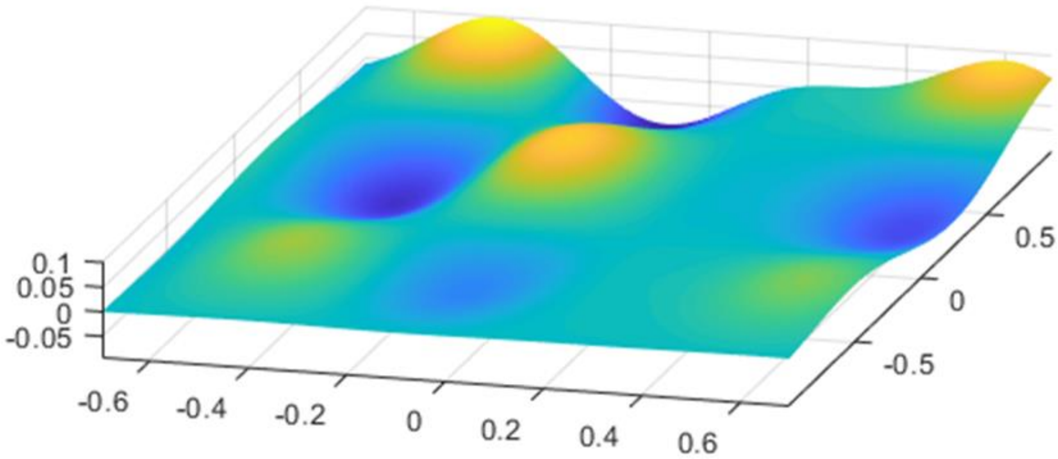


Figure 4.6: Reflection surface.

The frequency response is shown in Figure 4.7.

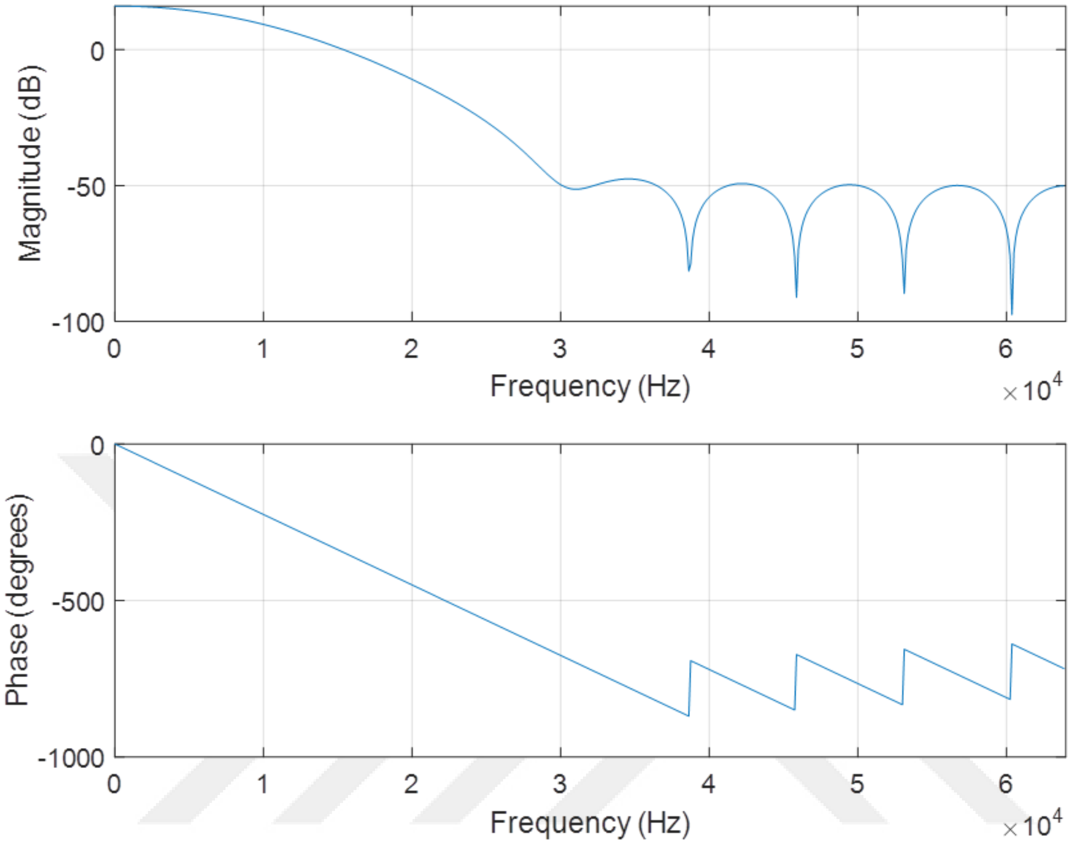


Figure 4.7: Frequency response of the model.

The impulse response for the plane surface with both direct and reflected sound is shown in Figure 4.8.

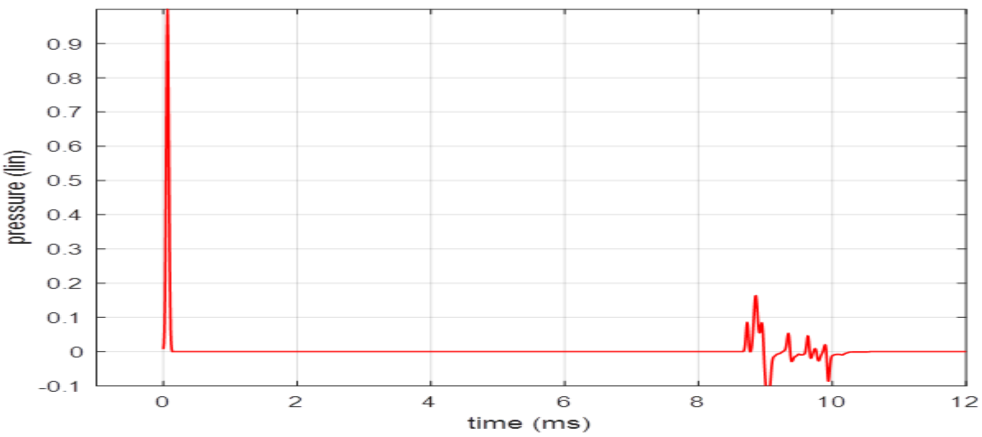


Figure 4.8: Total pressure

The parameter for the Fourier transform is shown in Table 4.5.

Table 4.5: Fourier transforms parameter

Parameter	Value
length of FFT required	2048
time gating to separate direct and reflected sound	677

The result is shown in Table 4.6.

Table 4.6: Results obtained from the model

Parameter	Value
sampling frequency	128000
number of samples removed from the array before the arrival of direct sound	2587
minimum sample number before reflection could have arrived	3272
Input pulse width variable	8

The graphical result is shown in Figure 4.9.

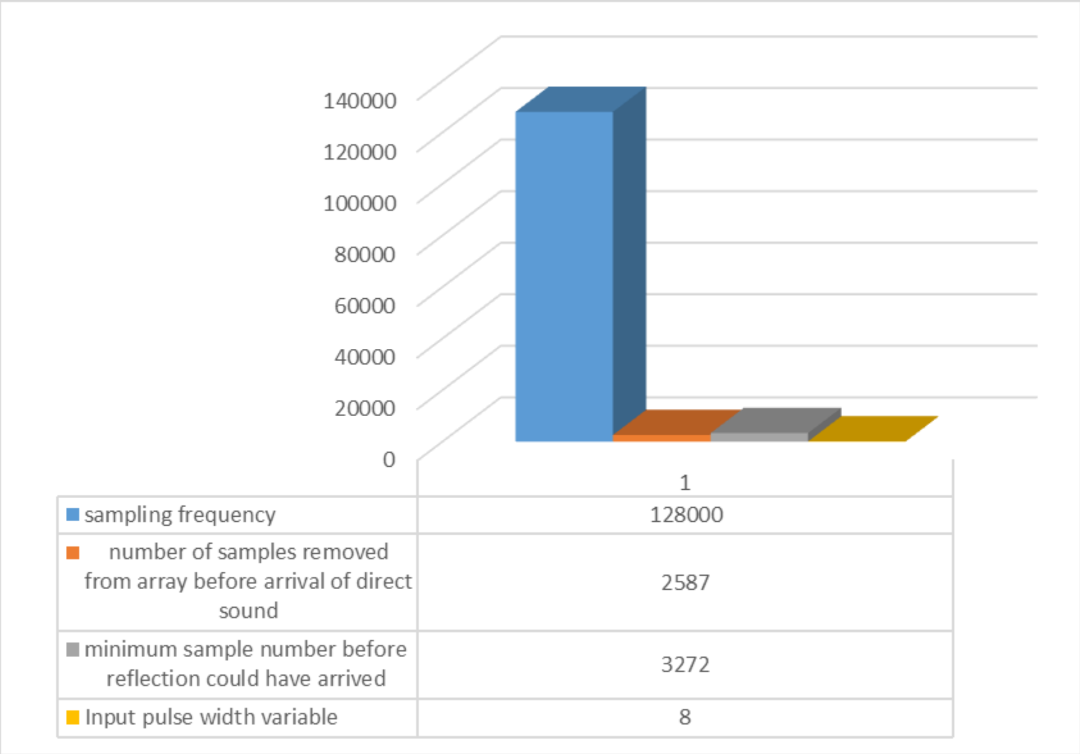


Figure 4.9: Graphical results

The ratio of scattered to incident pressure in decibels for the time domain (solid line) and frequency domain models (x) is shown in Figure 4.10. In addition to the shape of the rigid cylinder is shown in Figure 4.11.

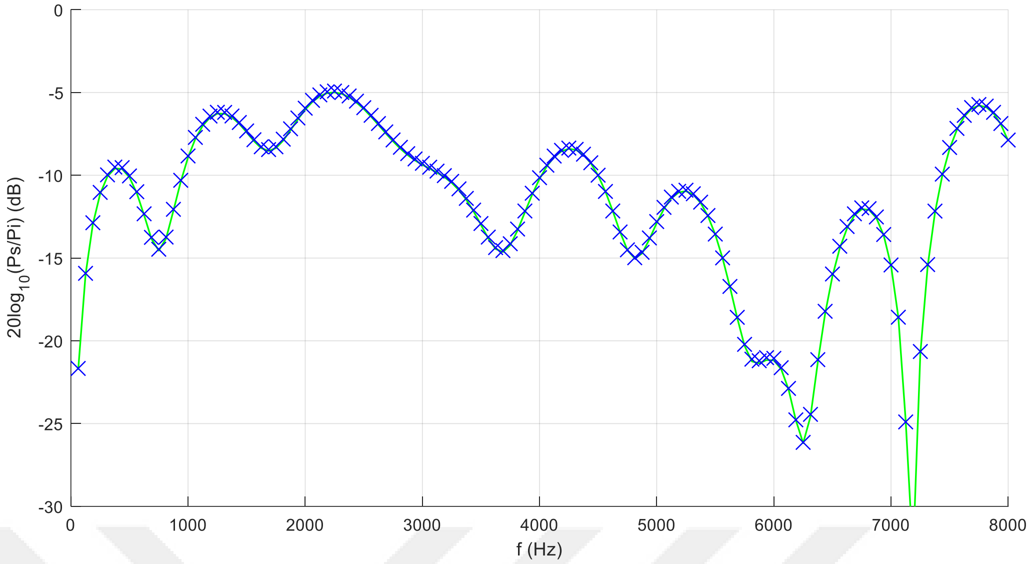


Figure 4.10: The ratio of scattered to incident pressure in decibels

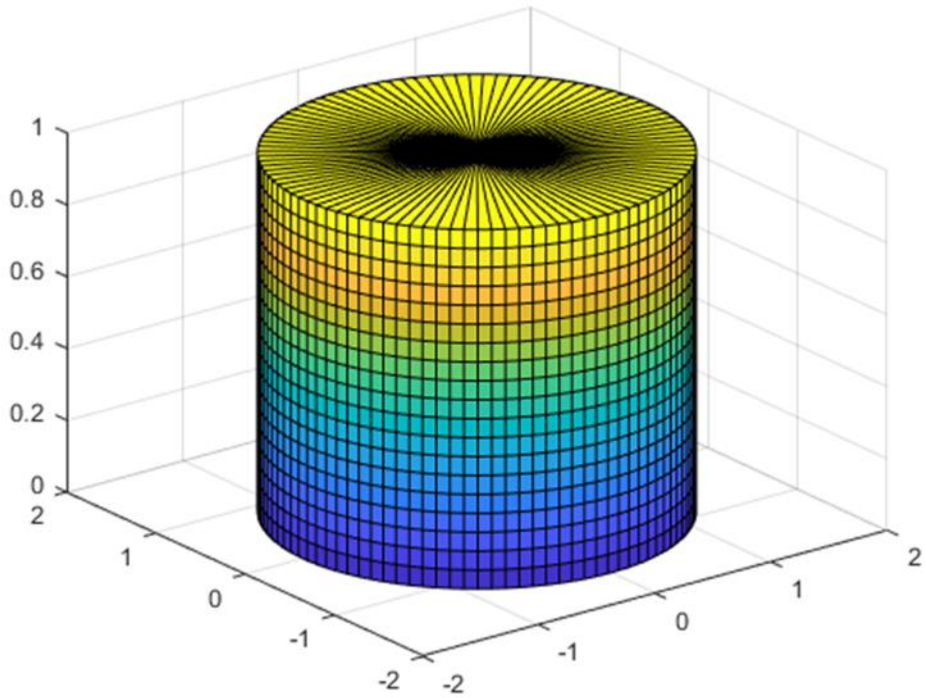


Figure 4.11: The shape of the rigid cylinder

CHAPTERE 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

This thesis presented the Bat algorithm optimization of the acoustics wave scattering gain reduction in the rigid cylinder. The overall system was created using MATLAB Simulink software. Bat algorithm was used to optimize the parameter of the cloaking material such as thickness, density, and the Poisson ratio of the cloaking material. A detailed and rigorous analysis was presented in the thesis. From the test results, the scattering gain is completed reduced in a cloaked cylinder than without a cloaked cylinder. Bat algorithm effectively optimizes the problem with less iteration, and the Bat algorithm is a suitable algorithm for this kind of problem.

The concept of reducing acoustic scattering is an important issue in modern society and in recent years, as it has been proven to be harmful to human and animal health. In general, there are many motivates to work and design systems to reduce the sources of noise pollution that comes from external surrounding such as systems of motor vehicle exhaust, vibrations of mechanical structural due to transfer the energy of acoustic waves through them, etc. Many researchers in the past decades and modern have used silencers to dissipate the acoustic energy traveling from one medium to another. Also, in our daily life, we see that there are other sources of noise resulting from systems of ventilation, air conditioning and heating. Carrying the air from one place to another and guiding it should be pushed by a system of fans that produce unwanted noise.

A scattering-cancelation method is followed in this analysis. We investigated the opportunity of minimizing acoustic scattering by elastic vibration based devices. The goal was to decide whether layers of elastic materials can be used to reduce the scattering significantly in the case of a rigid cylinder succumbed to regular plane waves. In the case of a multilayer coating, the method used to measure the distributed pressure field is described first. Then, the inverse problem of searching for the parameters of the layers that allow the acoustic scattering to be reduced is revealed. In the case of a bi-layer coating fixed on a rigid ring, results of numerical minimization using a Bat algorithm are provided.

5.2 Future Work

For future, we can recommend the other heuristic methods like gray wolf optimization, Whale optimization and Black widow spider methods. Also, for estimation, the scattering the deep learning and artificial neural network can be design and implement.

The efficiency of reducing acoustic scattering in this thesis by using elastic material layers around the cylinder is exceptional and a good tool for cancellation the acoustic scattering that led to reduce the acoustic noise in mechanical structures. Hence, we can suggest Multiple Scattering. The technique of Multiple Scattering can be applied by using several layers of different elastic materials and among them suitable fluid. Also, It is better to use different shapes such as a hexagon or octagonal cylinder, and we should focus our interest to see the performance of circular and/or polygon structure in case of acoustic scattering and radiation whenever we want to add more or less from several material layers. There are different results by using incident plane waves with distinct angles, which led to backscattering but in new figures. As is common in our work and daily study, there are many points or things still not achieved, improvements need a researcher to do it, practical experiments and laboratory applications Lacking to implement it. Bat algorithm optimization is used to improve and add new implementations and applications in laboratory fields.

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CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: Algburi, Zeyad
Nationality: Iraqi (IQ)
Date and Place of Birth: 29 April 1975, Baghdad
Marital Status: Married
Phone: +90 535 885 27 94
Fax: +90 535 885 27 94
email: engzeyad55@gmail.com

EDUCATION

Degree	Institution	Year of Graduation
MS	BVDU Mechanical Engineering	2013
BS	UT Mechanical Engineering	2005
High School	Al-Gomhoria High School, Baghdad	1998

WORK EXPERIENCE

Year	Place	Enrollment
2015-present	Ministry of Science and Technology	Phd. student
2012	Ministry of Science and Technology	Assis. Chief Engineers
2008	Ministry of Science and Technology	older engineer
2005 March	Ministry of Science and Technology	Mechanical Engineer

FOREIGN LANGUAGES

Advanced English

PUBLICATIONS

[1] Zeyad Algburi, Cihan Karataş, "Acoustic Scattering Reduction in Elastic Materials with Bat Optimization Algorithm", Journal Of Mechanical Engineering And Sciences, 2020.