

## **MODERN ACOUSTIC TECHNOLOGY RESEARCH IN NIGERIA: THE PRESENT, PROSPECT AND PROBLEMS**

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### **Abstract**

Acoustics, a science (vibration) of sound waves, due to its vast areas of relevance, has manifested into several branches of knowledge such as building and architectural acoustics, environmental acoustics, underwater (sonar) acoustics, biomedical acoustics, bioacoustics, musical acoustics, speech or language acoustics and a host of others. This study seeks to evaluate the studies undertaken in these areas in Nigeria with a view to identifying the progress and prospects of acoustic technology research (ATR). ATR refers to areas of applied research involving the application of acoustic technology or principles. An in-depth survey of related literature was conducted via Google search using relevant keywords while focusing on the articles published between 1990-2024. After thorough screening, seventy-three (73) articles were selected. From this selection, it is discovered that noise measurement and characterisation account for seventy-five (75) percent of the acoustic studies conducted in Nigeria over the past three decades. This result showed that ATR is still largely primitive in Nigeria. In the contemporary and emerging world, ATR now essentially gravitates towards the electroacoustic technology for various smart systems in all the identified diverse areas of application, as well as the development of novel acoustic materials from natural and locally available resources. Although there are little or no significant documented efforts presently, the modern ATR has a huge prospect in Nigeria. This paper discusses some of these prospects and highlights the challenges. It ultimately aims to stimulate interest among local researchers and research funding institutions in the area of acoustics to enhance the material and technological development in the country.

**Keywords:** *Acoustic technology, Piezoelectric materials, Couplant, Acoustic absorber, Acoustic impedance*

### **Introduction**

In the words of Nikola Tesla, a Serbian-American Engineer, if you want to find the secrets of the universe, think in terms of energy, frequency and vibration <sup>[1]</sup>. Arguably, no subject or field of research has directly related and manifested these three physical phenomena more profoundly than acoustic technology. Acoustics refers to the scientific study of sounds. Sound itself is the transmission of dynamic energy through a medium, which can be solid or fluid. This energy transfer occurs through the propagation of mechanical waves generated through the mechanism of vibration, causing the spatial movement of the particles within the transmission medium. Acoustic research deals with the application of this basic technology and scientific principle to solve physical problems. In the contemporary world, acoustic research has multifarious branches and has been successfully implemented in very vast number of areas. Among such areas are, but are

not limited to, environmental acoustics <sup>[2]</sup>, musical acoustics <sup>[3]</sup>, architectural acoustics <sup>[4]</sup>, biomedical acoustics <sup>[5]</sup>, bioacoustics <sup>[6]</sup>, underwater acoustics <sup>[7]</sup>, etc. UNESCO, in its 2010 report on *Engineering: issues, challenges and opportunities for development*, considered acoustics as one of the new areas essential to be included and taught in Engineering Education <sup>[8]</sup>.

### **The Modern Acoustic Technology and Piezoelectric Materials**

The discovery of piezoelectric materials and later advancements in their technology have made significant contributions to the advancement of modern acoustic research. Quartz was discovered in 1880 as the most abundant naturally occurring mineral in the Earth's crust, having a piezoelectric property <sup>[9]</sup>. This property enabled a material to deform when placed in an electric field, or conversely, generate an electric field when under mechanical stress. This tendency to change their shapes in the presence of electrical input enables the use of piezoelectric materials as a vibrator for generating acoustic waves in a fluid medium or motion in a solid.

Further efforts led to the development of synthetic man-made piezoelectric materials such as Roselle salt, ammonium dihydrogen phosphate (ADP) and lithium sulfate in the early 1940s. Later in the year, in 1944 and 1954 respectively, ceramic materials called piezoceramics, such as the polarised Barium titanate (BaTiO<sub>3</sub>) and lead zirconate Titanate (PZT), were also found to possess this property <sup>[10]</sup>. More so, polymer materials like polyvinylidene fluoride (PVDF) and polyacrylonitrile (PAN) were also found to exhibit this piezoelectric property. The piezoelectric polymers do not have excellent piezoelectric properties like the piezoceramics. However, they have better mechanical properties and biocompatibility, which are relevant for biomedical applications. Consequently, the polymers are combined with piezoceramics to form new materials called piezocomposites to further improve the desired material property of both classes <sup>[11]</sup>. These materials have more flexibility that enables them to bend easily and are readily conformable to any shape for wearable devices in biomedical applications <sup>[12]</sup>. The first research paper on piezoceramic/polymer composite using PZT powder and PVDF was first presented at the Japan IEEE conference in 1972 <sup>[13]</sup>.

These materials are used for producing various acoustic sensors and actuators in virtually all areas of application of modern acoustics. They are the active elements in the electroacoustic transducers used in underwater sound navigation and ranging (sonar) applications <sup>[14]</sup>. Underwater sonar is a very vast area of modern research covering applications such as oceanography, depth sounding, mine detection, surveillance of water territories against external invasion and threats, etc. Consequently, electroacoustic transducers have become an integral part of the development of ships, submarines, minesweepers, torpedoes, sonobouys, underwater autonomous vehicles and other naval security equipment <sup>[15]</sup>.

Modern acoustic research also entails the study, design and performance analysis of piezoelectric ultrasonic transducers for biomedical imaging and diagnosis, as well as non-destructive testing for various types of structural materials such as pipes in oil and gas <sup>[16]</sup>, concrete in building and construction<sup>[17]</sup>. In bioacoustics, piezoelectric microphones and hydrophones are used to characterise various behavioural adaptation mechanisms of different aquatic and terrestrial organisms using sound waves <sup>[18]</sup>. In all these current trends and advances in modern acoustic technology research, Nigeria seems to be an exception. Consequently, the current study seeks to evaluate the present status of acoustic research in Nigeria and then present the prospective areas

for indigenous researchers in accordance with the available level of expertise, technical know-how and facilities.

### **Methodology**

The reported finding in this systematic review is exclusively based on the journal articles, research reports and other relevant resources that are available online. Using topical elements in the title as well as other terms relating to the focus of the study as prompts in Google search, all relevant research files in PDF format were collected and carefully studied. With interest in the progress of acoustic research in Nigeria in the last thirty years, only those studies conducted between 1990 and 2024 were considered. These studies were classified into their various areas of acoustics. Based on that finding, the type, trend and tempo of research in acoustics were identified and discussed.

### **The Present Status in Nigeria**

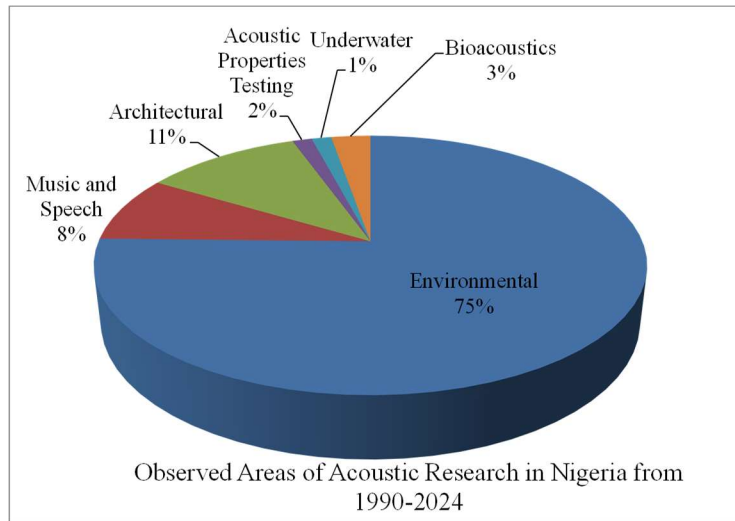
Onuu <sup>[19]</sup> presented the status of acoustic research in Nigeria in 2007. However, little or no much has changed since then in terms of the type and trend of the efforts documented. Compared to the rest of the world, it appears that the nature of the studies is still largely primitive, although there is a presence of a professional body, the Acoustical Society of Nigeria. Most acoustics-related research is focused on the anthropogenic noises coming from traffic, industrial, residential and occupational activities, machinery or equipment, as shown in Table 1.

**Table 1. Identified present areas of acoustic research in Nigeria and observed number of studies from 1990-2024**

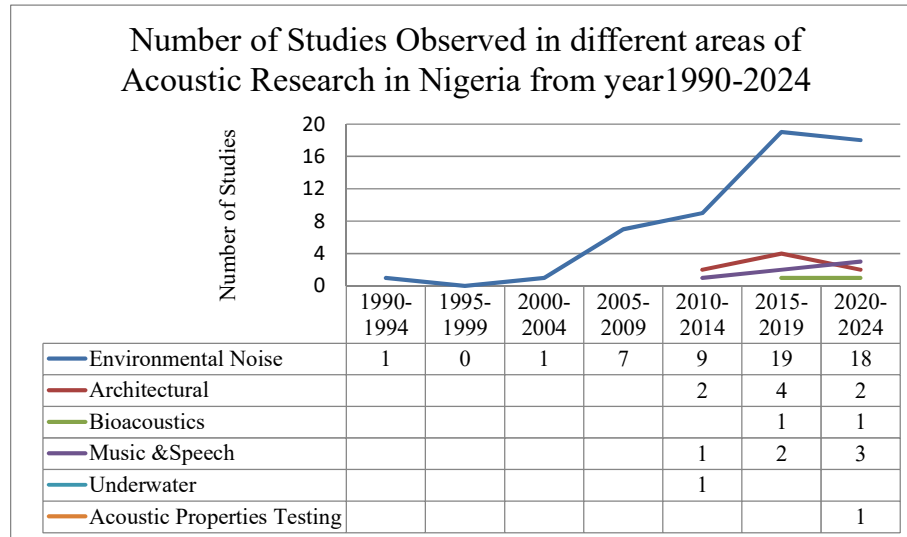
<b>Areas</b>	<b>Sub-categories</b>	<b>Number of Studies</b>
Environmental Noise	Metropolis & Traffic	27 <sup>[20-46]</sup>
	Residential Building	5 <sup>[47-51]</sup>
	Factories & Occupational	23 <sup>[52-74]</sup>
Music & Speech		6 <sup>[75-80]</sup>
Architectural (Building & Room)		8 <sup>[81-88]</sup>
Acoustic Properties Testing		1 <sup>[89]</sup>
Underwater		1 <sup>[90]</sup>
Bioacoustics		2 <sup>[91-92]</sup>

The literatures indicate that 75% of the 73 studies conducted in the areas of acoustic research over the last three decades (between 1990-2024) were on environmental noise (Figure 1). Apart from a few (less than 18%) that measured the impact of arbitrary noise level on the health and hearing impairment, most of these studies were mainly undertaken to measure the sound level and advise the government to regulate environmental noise pollution <sup>[93]</sup>. Meanwhile, the standard regulations on the permissible noise level have been in existence in Nigeria since 2009 <sup>[94]</sup>. It was gazetted under the National Environmental Standards and Regulations Enforcement Agency (NESREA)(establishment) Act 2007 of the Federal Government of Nigeria. Like in the case of any other policy in the country, the problem has always been the enforcement. These studies may be emphasising the renewed calls to reawaken the government to its public social responsibility of

taking measures to safeguard the health of its citizenry. Nevertheless, the finding also indicates that more attentions are required in other areas like bio-inspired acoustics, acoustic energy-harvesting, piezoelectric-inspired acoustic smart systems and a host of other areas to improve the material and technological development. As shown in Figure 2, about 70% of the entire studies observed on acoustics in Nigeria just began in 2015. This indicates an increasing trend and a higher probability of a more vigorous attention and further improvement.



**Figure 1. Percentage distribution of areas of research from 1990-2024**



**Figure 2. Trend of Acoustic research from 1990-2024**

### **The Prospective areas**

Acoustics is a subject of contemporary technological revolution that has tremendous potential to address many of the country's socioeconomic challenges. This section of the paper discusses critical areas where research on acoustics is currently needed in Nigeria.

### **Energy-harvesting**

Nigeria ranks among the countries with the highest energy access deficit in the world, with eighty-five (85) million of its citizens (representing 43% percent of its population) having no access to grid electricity <sup>[95]</sup>. Sound energy released into the environment as waste energy and a nuisance is one of the most untapped sources of renewable energy. From the prodigious data and information already provided from various existing research on environmental noise levels, a step can be taken to further develop the technology of acoustic energy harvesting. The tremendous potential of these energy sources and prospects of harvesting energy from environmental noise in Nigeria have been discussed <sup>[96]</sup>. The author mentioned the idea of exploring piezoelectric transduction technology and equally identified the associated challenge, such as small energy output. Nevertheless, he emphasised the relevance of such a small amount of energy as an alternative source to power microelectronics gadgets. Yet to date, there are no significant efforts in this direction.

Different methods have been proposed for harvesting acoustic energy and converting it into electricity. However, the use of a piezoelectric element has been reported as more effective and efficient than other techniques, such as electromagnetic and electrostatic <sup>[97]</sup>. One of the most common types, because of its relatively easier mechanism, is the piezoelectric cantilever <sup>[98]</sup>. A piezoelectric energy harvester structure is typically of two types, namely, the unimorph and bimorph <sup>[99]</sup>. Except that the bimorph structure utilises two layers of piezoelectric active materials with a metallic material substrate, both designs operate on similar principles and techniques. Copious literatures exist on this system, and interested researchers are encouraged to do further studies.

### **Storage and Preservation of Agricultural Products**

Agriculture plays a strong role in the Nigerian economy. With about 70.8 million hectares of land area for cultivating major crops such as maize, cassava, guinea corn, yam beans, millet and rice, agriculture contributed to 22.35 percent of the total Gross Domestic Product between January and March 2021<sup>[100]</sup>. Nigeria, with its vast agricultural potential, has long struggled with post-harvest losses, leading to significant food spoilage and economic wastage<sup>[101]</sup>. Some studies suggested that repeated transmission of shock waves can destroy some food-spoiling microorganisms, such as *Escherichia coli* <sup>[102]</sup>. Some other authors have also reported that mechanical vibration of yam tubers before storage can slow down the sprouting and thereby prolong shelf life<sup>[103]</sup>. Acoustic vibration techniques are also used in fruit ripening by vibrating the fruit with a small impact and then measuring the signal produced using a microphone or a piezoelectric sensor <sup>[104]</sup>. When sound waves propagate into dairy food, it leads to the formation, growth and collapse of micro bubbles<sup>[105]</sup>. According to the authors, low-frequency ultrasound (20-25kHz) generates stronger physical effects in liquid food systems, while above 2MHz, ultrasound induces stronger chemical reactions.

Other works have been carried out in acoustic energy and ultrasound technology for food processing and preservation. It was reported that piezoelectric transducers are majorly and commonly adopted than other types of devices because of their efficiency to transfer 85-95% of acoustic energy <sup>[106]</sup>. Control of the climate factors around agroproducts is one of the effective means of food preservation. Sonification or exposure of crops with storage problems like tomato (because of its higher rate of spoilage), to ultrasonic waves can lead to a spectacular solution.

### **Developing and Testing of Bio-inspired Acoustic Materials**

Efforts to reduce dependence on PZT and discover lead-free piezoelectric materials are ongoing. Apart from the fact that lead is carcinogenic, modern technology is vigorously shifting towards an eco-friendly concept in product development. Consequently, bio-inspired acoustic materials derived from agrowastes and bio resources have useful properties which make them relevant and potentially invaluable in different areas of acoustics applications. Some of the properties that are critical to acoustic applications are the density, speed of sound, characteristic impedance, Young Modulus, Bulk Modulus and Shear Modulus. A few of these major areas where relevant research effort can be intensified are highlighted in this section to increase awareness and interest among local researchers.

- **Sound-absorbing Materials**

Our daily lives are characterised by absorption, transmission, radiation and reception of sound. In many cases, these sounds are not desired and need to be removed or reduced. As the material within the environment or space plays a significant role in the reflection and absorption of sounds, the selection of material properties with the best relevant acoustic properties to serve as a sound absorber is an important subject in architectural and environmental acoustics. Many natural and eco-friendly waste materials that have excellent acoustic properties can be used to develop sound absorption products and utilities such as wall panels and furniture for rooms and buildings, whiteboards for classrooms, workbenches in mechanical workshops, fibre and particleboard for partitioning of offices, acoustic barriers against noise from highway traffic and factory equipment, car bodies and dashboards. Bamboo, wool, hemp, sugarcane, recycled paper, cardboard, wood shavings and sawdust, etc, are some of the prominent prospective materials on which many studies have been documented. Because of their higher porosity and biodegradability, a number of efforts have been made by foreign authors on some of these materials <sup>[107]</sup>, but there is much room to fill by Nigerian researchers. Where single materials cannot adequately provide the desired property, they can be combined with other materials to produce better, eco-friendly composite structures. For such, it may be necessary to determine transmission loss, sound absorption coefficient, intensity transmission and reflection coefficient, etc, as sound travels between the boundaries of two materials or from one testing medium to another. Meanwhile, the absorption coefficient in typical materials increases with both the frequency of sound and the thickness of the materials <sup>[108]</sup>. Hence, testing the newly developed sound absorbers at varying levels of these parameters may be a consideration in research methodology.

### **Couplants and Matching Layers**

Impedance matching is a crucial measure in any procedures or applications involving acoustic transmission between two media. This is because the acoustic waves are poorly transmitted when there is a wide difference or mismatch in the characteristic impedance-a product of density and sound speed- of the two media <sup>[109]</sup>. For effective sound signal transmission, there is needed for inserting a substance between the material under test and the transducer as a conducting or coupling medium <sup>[110]</sup>. This substance is called a matching layer in transducer design, and it is a solid material placed between the radiating piston head and contact surfaces <sup>[111]</sup>. It is usually made of polymer or metal-polymer composite such as urethane and epoxy materials <sup>[112]</sup>. Similarly, a liquid or gel-like material called couplant is a regular product used in non-destructive ultrasonic testing procedures <sup>[113]</sup>. It is usually placed at the interface of the transducer and the testing material. These materials typically have an intermediate acoustic impedance compared to the piezoceramic

and the transmission medium <sup>[114]</sup>. With active research efforts, novel matching layers and couplants can be developed from solid and liquid organic materials, respectively. The usual conventional approaches while conducting non-destructive testing are making use of any available common substance like vaseline, water or grease as couplant. It does not appear that any standard couplant is currently available in the Nigerian market. Consequently, research efforts to characterise relevant natural and waste sources, such as non-edible vegetable oils, aloe vera gel, etc, can lead to finding a standard alternative couplant. Rather than the synthetic materials like polyurethane often used, the development and testing of plastic-reinforced natural fibre composite products may provide a better substitute for matching layers. Several efforts have been documented in this area by non-Nigerian authors; indigenous researchers are only required to do further studies.

- **Medical Implants and Prosthetics**

Advancements in modern medicine have promoted the use of medical implants or implantable medical devices (IMD). These are devices that are placed inside or on the surface of the body, including prosthetics employed to replace missing body parts. The advancement of IMD technology has evolved over the years and yet still advancing to improve its performance and extend its useful lifespan. Meanwhile, one of the most critical considerations in this technology is the selection of materials for the development of IMDs. Among several other factors, biocompatibility is one of the major property considerations in IMD technology <sup>[115]</sup>. This refers to a state of quality that a device shall not produce a significant adverse effect at the placement site in the host's body. The ultrasound method has become the safest approach in the diagnosis and therapy of internal medical problems. Meanwhile, the considerable difference in impedances of the body and any implant may cause non-homogeneity within the body and significantly affect the effective transmission of ultrasonic waves. This underscores the need for research into new organic and eco-friendly agro products to replace synthetic materials like ceramics, metals, metallic alloys, plastic polymers, hydrogels, and their composites commonly used for medical implants. There is a prospect that animal products such as horns, bones, hoof, hide and feathers, etc. can be used to form a composite with other plant fibres from fruit seeds and shells to develop sustainable implantable devices. For instance, bone has been described as being piezoelectric in nature and is being incorporated to fabricate transducer devices and sensors for orthopaedic devices <sup>[116]</sup>.

### **Major Challenges**

This section highlights some of the factors responsible for slow progression in the major areas of acoustic research in Nigeria as compared to the rest of the world.

#### **Poor Funding and Equipment Deficit**

As it is generally known, funding is the major problem of research in Nigeria. Acoustic and vibration have become a special field of research in Mechanical or environmental engineering involving some laboratory equipment. Most of these institutions that engage in acoustic research lack the financial resources to procure materials and equipment to set up a standard laboratory. In fact, emerging facts revealed that there is no standard acoustic laboratory in Nigeria at present. Some of the major equipment for acoustic technology research are highlighted in Table 2.

Table 2. Some major equipment in a modern acoustic laboratory

<b>Purpose</b>	<b>Names</b>	<b>Uses</b>
Sound Measurement	Sound level meter	Measure sound pressures (dB)
	Octave Band Analyser	Measure sound level in a specific frequency range
	Spectral or Fast Fourier Transform (FFT) analyser	Measure sound frequency content
	Noise dosimeter	Measure personal exposure to noise
	calibrators	Ensure accuracy of measurement equipment
Acoustic testing	Speakers	Generate or simulate sounds
	microphones	Measure sound pressure, intensity and frequency
	accelerometers	Measure vibration and acceleration
	Impedance Tube	Measure acoustic impedance
	Impedance analyser	Measure signals at different frequencies
	Reverberation chambers	Test sound reflection and absorption
	Signal generators	Generate test signals
	Audio analyser	Measure audio signals and distortions
	Software (MATLAB, LabVIEW, FEA (Pzflex, ANSYS, COMSOL, etc)	To simulate and optimise designs
	Acoustic transducers of several types and	To introduce acoustic signals



	frequencies	for testing
Vibration measurement	Vibration meters	Measure vibration amplitude and frequency
	Laser vibrometers	Measure surface vibration
	Modal analysis equipment	Analyse modes of structural vibration
	Shakers (electrodynamic and hydraulic)	Vibrate testing materials
	Acoustic hammer	Initiate acoustic excitation

### **Little Understanding of the Technicalities**

Acoustics is an applied science which involves a lot of technicalities, especially as it relates to engineering and technology. Although the fundamental theories and principles are contained in standard texts and literature, a lot of local researchers lack the specific technical skills for implementation. Meanwhile, there are currently few specialists and experts in this area in Nigeria who can give the proper mentoring required.

### **Low Opportunities for International Collaboration**

The abysmally low level of technology in most of the acoustics research in Nigeria has isolated most Nigerian researchers from the rest of the world in terms of new advances and recent trends. More so, a larger percentage are constrained from attending conferences or finding postdoctoral, visiting or sabbatical positions in foreign institutions due to their lack of resources and low quality of their research outputs in the area. Generally, participation in conferences is becoming the least priority, if at all given any consideration, among Nigerian academics and researchers due to poor institutional sponsors and motivations. Consequently, there is no significant collaboration among Nigerian researchers and their international counterparts. Such collaboration could have enhanced skill, knowledge and technology transfer.

### **Conclusion**

Research in acoustics technology is still developing in Nigeria. There have been significant efforts in the last twenty years that show a positive trend for the future. However, the field is not as advanced as in other parts of the world. Prospective areas of modern acoustic technology research which would directly improve the socioeconomic and technological development in Nigeria have been discussed. Finally, the various challenges hindering the steady progress of this important area of study are enumerated. The foremost and most critical is the lack of essential instruments and facilities for the attention of private, public and corporate funding agencies.

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