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The Journal of Acoustical Society of India

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ARTICLES

INFORMATION

FOREWORD

It is with great pleasure that we present this special issue of the *Journal of Acoustical Society of India* (JASI), Volume 51, Number 2, April 2024. This edition offers a rich exploration of contemporary research and innovations in acoustics, blending the traditional with the cutting-edge to address both Indian and global challenges in the field.

The articles in this issue span a wide array of subjects, from the profound scientific studies of **Sir C.V. Raman's work on Indian musical instruments**, to the **integration of intelligent algorithms in hearing aids** for better acoustic experiences. The insights on **global and Indian traffic noise abatement strategies**, as well as the **comprehensive analysis of noise mapping** from diverse regions, offer both scientific and practical contributions toward improving our sonic environment.

Further studies delve into the impact of **voice-altering software on original voice signals**, a critical topic in today's digital age, and the innovative role of **sensor systems in healthcare**, drawing parallels between Indian and global perspectives.

This special issue is a testament to the continued commitment of researchers to push the boundaries of acoustic science and technology. We are confident that the knowledge shared within these pages will inspire further discourse and innovation in the field.

We extend our gratitude to the authors, reviewers, and contributors whose dedication has made this issue possible. We hope this edition serves as both a valuable resource and a catalyst for future advancements in acoustical research.

Dr. Mahavir Singh
Managing Editor, ASI

Dr. B. Chakraborty
—Chief Editor, JASI

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An exploration of the scientific studies of Sir C.V. Raman on indian musical instruments

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ABSTRACT

Sir C. V. Raman, the renowned Indian physicist from the golden era of physics, explored a wide spectrum of scientific endeavors, spanning from the theoretical underpinnings of musical instruments to the phenomena of light scattering and ultrasonics. Although there is no photograph that shows Raman with a drum, it is noteworthy that during his youth, Professor Raman harbored a significant interest in the physics and artistic essence of the Mridanga, violin and Indian drums, as is evident from a number of his seminal papers. Even prior to delving into the study of light scattering, which although brought him the Nobel Prize in 1930, Raman harbored a profound fascination for waves-specifically, sound waves. This interest in waves most likely stemmed from his father, R. Chandrasekhara Iyer, who not only taught Physics and Mathematics but also possessed adept skills as a violinist. It is thus obvious that this environment nurtured Raman's inclination towards understanding the physics of sound waves, especially considering he himself played the violin. At the tender age of 16, while attending Presidency College in Madras, Raman embarked on his journey into acoustic research. Although the interdisciplinary nature of studies is common nowadays, the scenario was not the same 100 years back, Raman being one such visionary who was fascinated in this intermingling of art and Science, while looking for the Science of Music at a very young age. This paper is essentially a review of the various scientific works done by Sir C.V. Raman on different stringed and percussion instruments of Indian origin, and how these works have laid the path for extensive research on these instruments in later years as well as till date.

1. INTRODUCTION

It was during the time that Sir C.V. Raman spent in the Indian Institute for Cultivation of Science, Kolkata where he delved deep into music. He was not a mere music enthusiast, he went much beyond that. Raman was interested in how sound and notes were produced to create a complementary effect of art and science. The exploration of the scientific aspects of music has a longstanding history. In the 1890s, the renowned British physicist Lord Rayleigh, who later gained fame for discovering the element Argon in 1904, conducted initial experiments on the vibrations emanating from bells. Raman, captivated by the depth of acoustical knowledge present in ancient Indian traditions, marveled at the insights gained over the ages. Motivated by Lord Rayleigh's research, Raman delved into the world of Indian percussion instruments, specifically the mridangam and tabla. His curiosity was further enhanced by what he perceived as a 'remarkable appreciation of acoustical principles' deeply ingrained in ancient Indian practices. Through his investigations, he discovered that this understanding was intricately connected to the construction techniques employed in crafting these instruments.

His initial inquiry revolved around whether the captivating musical resonance produced by the veena stemmed from sentimental attachment or had a tangible physical basis. Raman scrutinized the construction of the veena's bridge, noting its ingenious design that defied the Helmholtz law, which dictates that the plucking position on a string cannot be a node. Consequently, the veena generates a plethora of harmonics, rendering its sound akin to the richness found in the human voice.

Raman's essay, "The Acoustical Knowledge of the Ancient Hindus," not only provides a remarkable insight into the mindset of creative musicians in ancient India but also presents a scientific exploration of aesthetic interpretation that holds relevance in the history of ideas. In this essay, Raman mentions "Music, both vocal and instrumental, undoubtedly played an important part in the cultural life of ancient India. Sanskrit literature, both secular and religious, makes numerous references to instruments of various kinds, and it is, I believe, generally held by archaeologists that some of the earliest mentions of such instruments to be found anywhere are those contained in the ancient Sanskrit works. Certainly it is that at a very early period in the history of the country, the Hindus were acquainted with the use of stringed instruments excited by plucking or bowing, with the transverse form of flute, with wind and reed instruments of different types and with percussion instruments. It is by no means improbable that India played an important role in the progressive Evolution and improvement of these instruments and might have served as a source from which their knowledge spread both eastwards and westwards." In this essay, Prof Raman provides an overview of the preliminary scientific investigations made by him regarding the acoustics of Indian percussion instruments and why they have been widely used to produce a long sustaining aesthetic effect.

It's intriguing to note that many Western percussion instruments primarily generate noise. For instance, Lord Rayleigh's research revealed that the air trapped within the shell of a kettle drum doesn't significantly alter the pitch relations of its musical overtones in a pleasing manner. However, Raman's keen musical ear detected harmonious overtones in the sound of the Mridanga, highlighting the distinct acoustical properties of Indian percussion instruments like the Mridangam and Tabla compared to their European counterparts.

Furthermore, he showcased how maestros like Palghat Mani Iyer could elicit sounds from the Mridanga akin to those of stringed instruments. In his paper on "The Indian Musical Drums," Raman elucidated how these drums provided a practical solution to the acoustical challenge of transforming inharmonic overtones into harmonic tones. He described the construction of the drumhead, which involved layering a mixture containing finely powdered iron over the surface to adjust its density. The resulting inhomogeneous membrane exhibited remarkable acoustic properties, producing harmonious vibrations with various nodal patterns. Raman's work sheds light on the integral role of percussion instruments like the Mridangam and Tabla in Indian musical compositions, emphasizing their contribution to creating a musically unified whole. This perspective holds relevance not only in traditional Indian music but also in contemporary fusion genres, where the integration of diverse musical elements echoes the harmonious blend exemplified by Carnatic-Hindustani Fusion Music (Jugalbandi).

2. ON THE INDIAN MUSICAL DRUMS

Raman's seminal paper on "The Indian Musical Drums" published in 1935 gives a detailed description of the results obtained by him in the year 1919 which showed that in the Indian musical Drums we have a circular drum-head which is loaded and damped in such a manner that all the overtones above the ninth are suppressed and these nine are grouped in such a manner as to give a succession of five tones in harmonic sequence. Raman's acute ear and profound musical interest enabled him to discern these harmonic overtones in the percussive sounds of the mridangam and tabla. The drumhead's vibrations exhibit a remarkable parallel to a stretched string producing its initial five harmonics; as the drumhead

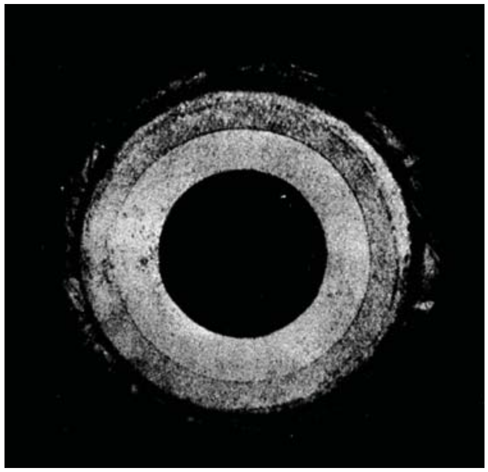

Fig. 1. Drumhead giving musical overtones (Raman & Kumar, 1920)

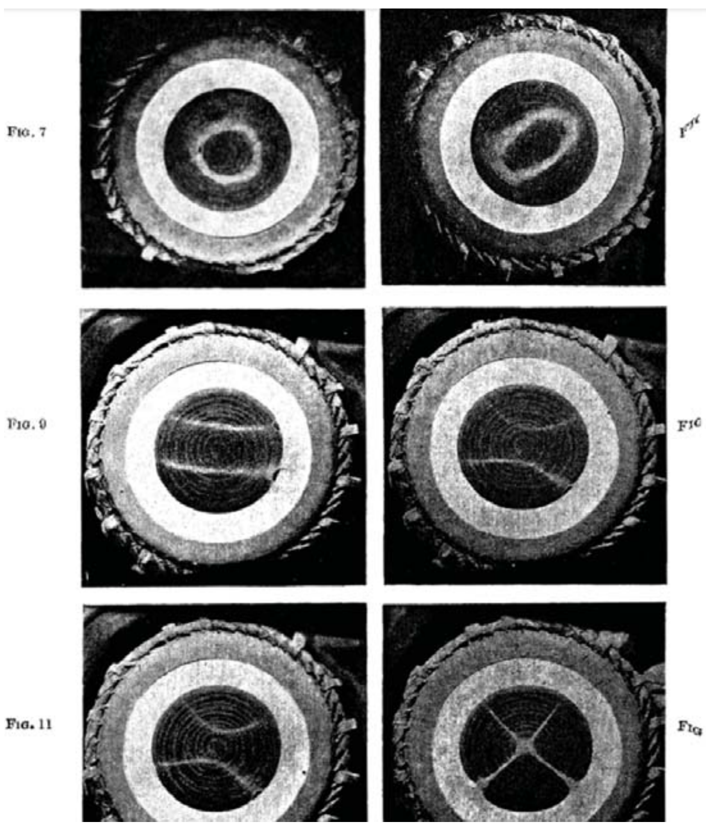

Fig. 2. Vibration patterns with sand on sahi-loaded drumhead (Raman, 1934)

vibrates, it naturally divides into 1, 2, 3, 4, or 5 sections, resulting in the respective harmonics. The third, fourth and fifth harmonics arise from the superposition of 2, 2 and 3 respectively, of the normal modes of vibration. These combined forms of vibration are easily visualized and illustrated through sand figures as shown in the paper. Through his research, he uncovered that the varied loading of their membranes could evoke harmonics, thereby likening the mastery of Indian drums to that of stringed instruments.

3. ON THE DIFFERENT STRINGED INSTRUMENTS OF INDIAN ORIGIN

"On some Indian Stringed Instruments" is another paper published in 1921 which illustrates the keen interest of Raman in the genre of Indian instrumental music. Raman's keen ear for music detected the presence of overtones which normally should not exist in the case of plucked stringed instruments. Raman discovered that the bridge of the Veena has been so designed by the ancient Indians that both of the deficiencies mentioned above are overcome. In the Veena, the upper surface of the bridge is curved, allowing the strings to pass over it tangentially without forming sharp angles. Interestingly, in this bridge design, the overtones don't diminish more rapidly than the fundamental tone; instead, they steadily amplify relative to it. Furthermore, even overtones with nodes at the point where the string is plucked-contrary to Helmholtz's law-can be distinctly heard on a Veena. Professor Raman attributed these intriguing phenomena to the periodic contact between the curved surface of the bridge and the string. This periodic contact enhances the overtones while slightly diminishing the fundamental tone due to the regular transmission of impulses between them.

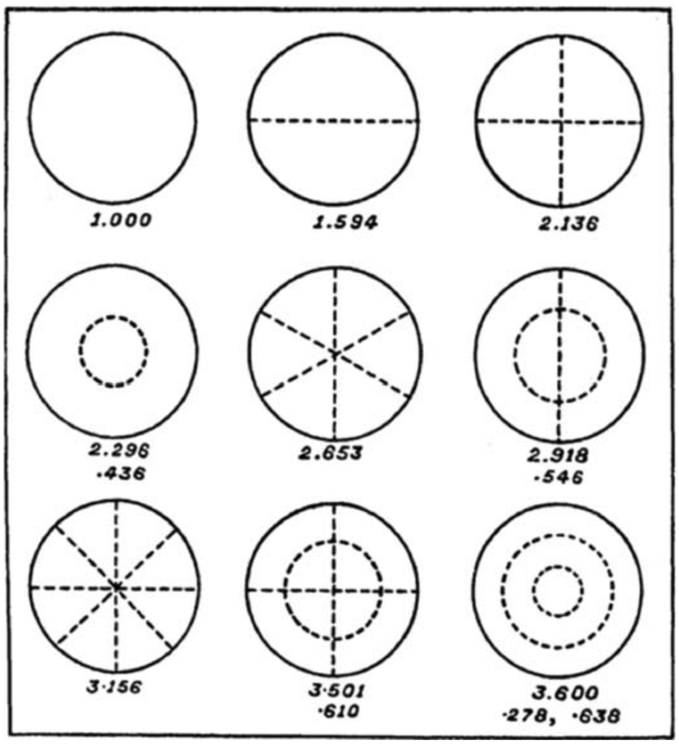

Fig. 3. Normal modes of Uniform membranes (Raman, 1934)

This paper essentially documents the difference in bridge structure between the *tanpura* and the *Veena*, which is essentially the reason for the difference in tone-quality. The paper discusses the form of the bridge adopted in the Veena that differs from the bridge of the Tanpura in two respects. The upper curved surface of the bridge in the Veena is of metal and the special mode of adjustment of contact by means of a thread used in the Tanpura is dispensed with and the string merely comes off the curved upper surface of the bridge at a tangent. The bridge of the Veena is also much higher above the body of the instrument than in the Tanpura. Even when the strings are pressed down on the frets when the instrument is being played, the curvature of the upper surface of the bridge ensures the string always leaves the bridge at a tangent to it. In attempting to find an explanation for the difference in tone-quality produced by the special form of bridge. the author made a surprising observation. namely, that in the tone of the Tanpura or the Veena

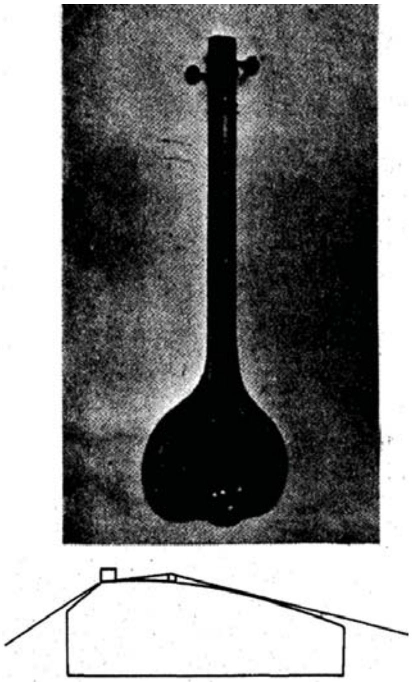

Fig. 4. Tanpura and its bridge

Fig. 5. Veena and its bridge (Raman, 1921)

overtones may be heard powerfully. according to known acoustical principles. should have been entirely absent. According to the law enunciated by Young and Helmholtz, if the string is plucked at a point of 16 aliquot division, the harmonics having a node at the point of excitation should be entirely absent. This law may be readily verified on an ordinary sonometer with the usual form of bridge. For this purpose, the position of the node should first be found exactly by trial, by putting the finger in contact with the string and plucking elsewhere so as to elicit the overtones desired. Having found the position of the node, the string should be plucked exactly at that point and then again touched with the finger at the same point. On an ordinary sonometer, this results in the sound being immediately quenched in as much as the finger damps out all the partials except those having a node at the point touched, and the latter are not excited in the first instance in accordance with the Young-Helmholtz law. On trying the same experiment with the Veena or the Tanpura, it will be found that the overtone having a node at the plucked point sings out powerfully. In fact the position of the plucked point hardly appears to make a difference in regard to the intensity of the overtones in the Tanpura.

This remarkable result is not due to any indefiniteness in the position of the node point as the latter is found to be quite well defined as is shown by the fact that in order to demonstrate the effect successfully, the string must be plucked and then touched exactly at the right point otherwise the sound is quenched. We are thus forced to the conclusion that the special form of bridge is completely to set aside the validity of the Young-Helmholtz law and actually to manufacture a powerful sequence of overtones including those which ought not to have been elicited according to that law". "Some photographs of the vibration curves of a Tanpura string showed that as a consequence of the grazing contact at the bridge, the vibration of the string decreased in amplitude and altered its form at a much more rapid rate than when the grazing contact was rendered ineffective. From first principles it is obvious that in the Tanpura the forces exerted by the string on the bridge must be very different from what they would be for a bridge of ordinary form. It seems probable that by far the greater portion of the communication of energy to the bridge occurs at or near the point of grazing contact. The forces exerted by the string on the bridge near this point are probably in the nature of impulses occurring once in each vibration of the string. This would explain the powerful retinue of overtones including even those initially absent in it. There will, in fact be a continual transformation of the energy of vibration of the fundamental vibration into the overtones".

4. TRAILING ON THE LINES OF RAMAN

The pioneering works of Raman on the physics behind Indian percussion and stringed instruments were later continued in greater detail by other scientists. Music research on instruments as well as in the vocal genre continued in different ends after this, although not in a very conglomerate form. Bhattacharya *et al.* (1956) worked on the vibrations of *tanpura* strings using simple photographs to establish the difference in vibrating strings. Photographs were taken after successive time intervals when the string of the tanpura of length 88 cm was plucked at $1/6^{th}$ of its length. From the photographs, authors conclude that the curves are very complex and rich in overtones. Also they note that the complexity of the vibration increases with time. But, without the *jwari*, the vibrations of the tanpura string reduces to that of an ordinary type of stretched vibrating plucked string in which only the amplitude decreases with time.

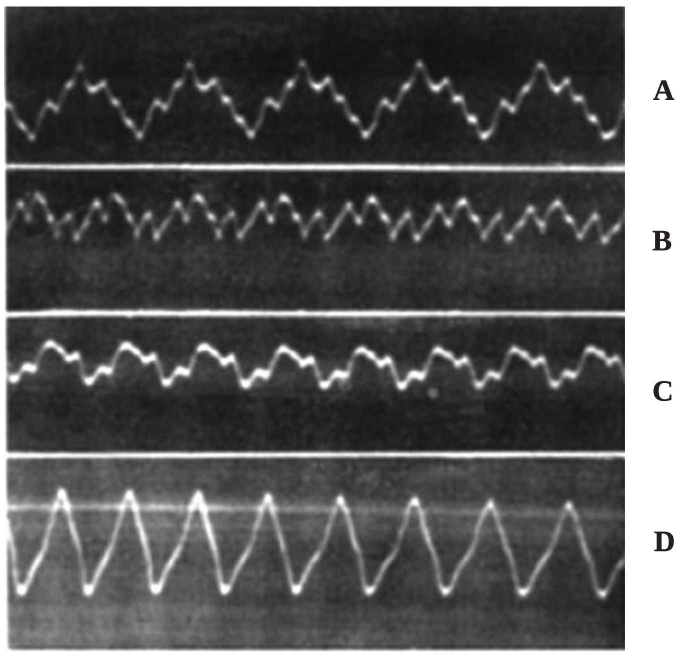

Fig. 6. Vibrations of tanpura strings (Bhattacharya *et al.*, 1956)

A few studies have dealt with the meaning making process of Indian music, processing and analyzing the use of melody into various emotional appraisals (Deva, 1956; Deva & Virmani, 1968). The spectrum analysis of the tones of *tanpura* presumably was done for the first time by Janakiram and Yegnarayana (1977), who correlated the acoustical findings with that of perceptual evaluation parameters. Their analysis revealed the presence of several notes which are normally overlooked even by a professional artist. The authors tried to explain the effect of bridge in Tambura or *jwari*, as mentioned earlier, in producing the so-called "live tone" through time and frequency parameters of *tanpura* sounds. Modak and Desa (1965) studied the effect of this bridge or *jwari* in more detail in their spectral analysis.

In the same timeline, when Raman was working on percussion instruments, another scientist Dr. R.N. Ghosh working in Muir College, Allahabad published his theory on the vibrations of centrally loaded musical drums in Physical Review journal (Ghosh, 1921). His theory focused on two main aspects, when the load varies inversely as the first power and as the second power of the distance from the center. Ghosh established theoretically that in the second case the partials form a harmonic series, whereas in the first case they do not. In a continuation of Raman's seminal paper on musical drums of India, Rao (1938) provides a discussion of the normal modes of vibration of a symmetrically loaded membrane in which the surface density varies as an inverse fractional power of the radial distance from the center, with a view to ascertain how far a law of density of this type enables the harmonic sequence of tones observed in the Indian musical drum to be approximated to. Rao demonstrates with the help of various mathematical calculations that a highly concentrated loading at the center cannot succeed in reproducing completely the observed results. This indicates that a more widely distributed load which is actually employed in real time scenarios should theoretically be necessary to achieve the desired purpose. Ramakrishna and Sondhi (1954), belonging to the same Institute of Science, Bangalore from where Raman retired, developed a theory of drums assessed by Raman in their paper on the basis that the drumheads of these instruments are regarded as circularly symmetric membranes with a radial step discontinuity in the density. The authors essentially provided a mathematical verification of Raman's theory by computing the eigenvalues and eigenfunctions of a composite membrane, and then using numerical calculation they show that for suitable ratios between the densities and radii of the two parts, the frequencies and the modes of vibration are in accordance with Raman's observations. Ramakrishna and Sondhi's works were further extended by Sarojini and Rahman (1958) of the same Institute. They essentially compared the concentric loadings in the right tabla and the eccentricity of loading in the left tabla by the method of variation of parameters incorporating the variation of the surface density of the drumheads in the normalizing integral. The authors show that the harmonic character of the modes of vibration is primarily determined by the ratio of the radii of the loaded and unloaded regions, the eccentric placement of the loaded region in the left-hand tabla merely bringing about a small separation between the frequencies of the even and odd modes.

5. CONCLUSION

Sir C. V. Raman as a scientist was a man who epitomized his times, belonging to an era where the boundaries between science and art, tradition and modernity remained fluid. His profound appreciation for science as a fundamentally human endeavor fueled his interest in the arts, wherein he tried to bridge the two disciplines using his scientific endeavor. Raman believed that Indian percussion instruments possessed a certain subtlety that complemented the abilities of skilled singers or musicians playing the flute or violin, which initially inspired his study. Fascinated by the intricate qualities of the music he encountered, he felt compelled to delve deeper into its exploration. Famously quoted, Prof Raman once remarked, "Pose the right questions, and nature will unveil her mysteries." Similarly, in his case, music acted as a gateway, revealing its melodic secrets.

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Better acoustics and intelligent algorithms : Recent trends in hearing aid preference

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ABSTRACT

The utilization of hearing aid prescription statistics offers significant insights into the trends and effectiveness of hearing healthcare services. By analyzing these statistics, researchers and clinicians can identify trends in hearing aid adoption, compliance, and patient demographics. This data-driven approach enables the assessment of the efficacy of different hearing aid technologies and fitting protocols, facilitating continuous improvement in user satisfaction. The hearing aid prescription statistics can also highlight disparities in access to hearing healthcare, guiding policymakers to allocate resources more effectively towards underserved populations. This study focuses on the analysis of hearing aid prescriptions from 2014 to 2024 at the All India Institute of Speech and Hearing, Mysuru. Older adults (65-80 years) and children younger than 10 years accounted for more than 70% of the cases, indicating the population segments that need to be specifically targeted. The gender distribution was biased towards males (70%), indicating a higher risk for hearing loss-both congenital and acquired (e.g., occupational hearing loss, presbycusis). Interestingly, there was an increase in subjective preference for Receiver-in-the-Canal (RIC) aids (versus Behind-the-Ear aids) from 15.5% in 2019 to 31.8% in 2024, attributed to the more natural acoustics and reduced occlusion effect offered by RICs. Additionally, during the fine-tuning of hearing aids, two issues were most prominent: listening in noise and own voice perception. Consequently, hearing aids with advanced noise reduction algorithms, such as adaptive directionality and differential own voice processing were more frequently preferred. These findings suggest that better acoustics and AI-driven adaptive processing should be increasingly prioritized in hearing aid research.

1. INTRODUCTION

Hearing loss is a global health concern that affects individuals across all age groups, with significant impacts on children and older adults[1,2]. As our understanding of the importance of early intervention and proper amplification has increased, so too has the technology available to address hearing impairments. Hearing aids, the primary intervention for many forms of hearing loss, have undergone rapid advancement in recent years, evolving from simple amplification devices to sophisticated, AI-driven systems capable of adapting to complex auditory environments[3]. This progression in hearing aid technology, coupled with changing demographics and increased awareness of hearing health, has led to shifting trends in hearing aid procurement, usage, and user satisfaction[4].

This study aimed to understand these trends by analyzing data on hearing aid procurement and user feedback over a ten-year period by examining factors such as age distribution, gender differences, and transitions in hearing aid preferences. Further, this research highlights the changing nature of concerns of the user and preferences and offers insights on how technological advancements are addressing user needs. As our population ages and our environment becomes noisier, the ability to effectively address hearing loss becomes crucial. Thus, understanding these trends is crucial not only for audiologists and hearing aid manufacturers but also for policymakers and healthcare providers.

2. MATERIAL AND METHODS

The data analysed in this study is derived from the hearing aid procurement and user feedback data from 2014 to 2024 at the All India Institute of Speech and Hearing, Mysuru. The data was anonymized, categorized by gender, hearing aid type, concerns reported by the hearing aid users, and associated digital processing algorithms preferred over the years. Only over the ear hearing aids were considered for the study since body-level hearing aids, and In-the-ear hearing aids together account for just 6.5% of total hearing aid prescriptions. Hearing aids procured for all degrees and types of loss were considered for analysis.

3. RESULTS AND DISCUSSIONS

3.1 Effect of age

Older adults (65-80 years) and children younger than 10 years accounted for more than 80% of the users, indicating the population segments that need to be specifically targeted (Figure 1). Older adults (60-80 years and beyond) and children younger than 10 years accounted for more than 70% of the users, indicating the population segments that are especially in need and should be specifically targeted for awareness, screening, and evaluation programs. Children with congenital hearing loss or early acquired hearing loss require early and effective amplification to ensure optimal speech and language development[2]. Older adults experience a progressive reduction in hearing sensitivity with age, and should not be ignored. Early hearing aid fitting in older adults has been linked with better social interaction, better mental health, and lower risk for dementia[1].

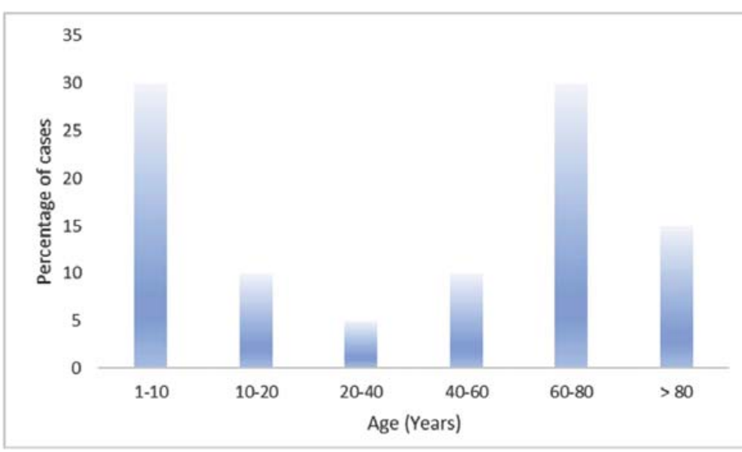

Fig. 1. Distribution of hearing aid procurement across age groups.

3.2 Effect of gender

The gender distribution was biased towards males such that only 32% of the hearing aids procured were by females. A Poisson test for rate ratio was performed which indicated a rate ratio of 0.47 (Z = –11.1; p < 0.001). There was thus a significant gap between male and female hearing aid procurement: the rate in females was only 47.1% of that of males. The gender distribution was biased towards males (70%), indicating a higher risk for hearing loss-both congenital and acquired (e.g., occupational hearing loss, presbycusis)[5]. It is important to realize that these figures do not directly represent the risk for hearing loss, but is more a measure of help-seeking behavior among the two genders. It is possible that men, in general, are more active in seeking correction for hearing loss than females in the Indian scenario[6]. Awareness programs need to be designed to specifically encourage women participation in seeking amelioration of hearing loss related reduction in quality of life.

3.3 Transition in the type of hearing aid preferred

To track the changes in preference over the years, hearing aids prescribed from 2014-2019 were compared to those prescribed from 2019-2024. Specifically, the Behind-the-ear (BTE) hearing aid prescription was compared with those of the more advanced Receiver-in-the-canal (RIC) hearing aids (Figure 2).

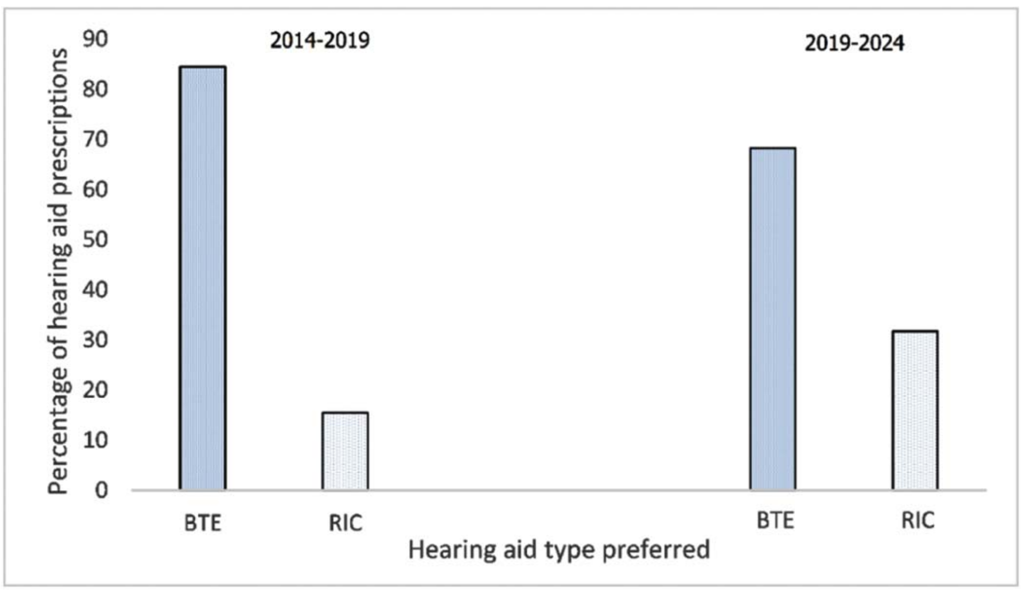

Fig. 2. Changes in over-the-ear hearing aid preferences over the years.

Subjective preference for RIC hearing aids (versus BTE aids) increased drastically from 15.5% in 2019 to 31.8% in 2024. This came at the cost of reduction in preference for BTE hearing aids. More natural acoustics and reduced occlusion effect offered by RICs may be the reason for this change. The BTE sound quality is affected by the additional resonances introduced by the tubing, which is absent in the RICs. Also, the RICs offer a more open fit, allowing for better ventilation and more natural low frequency and own voice perception due to the venting effect[7]. If the degree of loss is severe or higher, however, a higher gain and tighter fit may be necessary. In this case, BTEs may be preferred over RICs.

3.4 Fine-tuning of hearing aids in the last five years: primary concerns

From 2014-2019, the main concern during the fine-tuning was related to the hearing aid-gain: need more gain (32.5%) and need lesser gain (44.5%). The other concerns included speech in noise perception

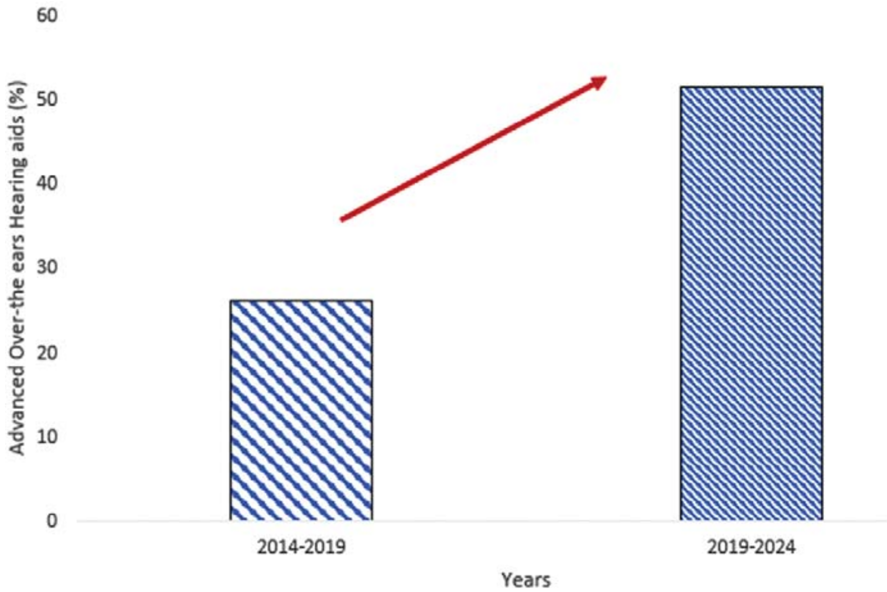

Fig. 3. Increase in preference for hearing aids with advanced digital processing algorithms over the years.

(16.2%), feedback issues, battery drain, and hearing aid fit. However, the primary concern in the last five years shifted to speech in noise perception (40.7%) and gain-related issues (35.7%). The new entry was the perception of own voice-related ratios (5.7%). This correlated with the increased preference for hearing aids with AI-driven adaptive processing, including multi-directionality, adaptive digital noise reduction, and differential own voice processing (Figure 3) despite an average cost increase of Rs 5300 for these hearing aids. The rate ratio of acquisition of advanced digital hearing aids modeled with a Poisson distribution indicated a 51.2% increase in preference over the five-year period ($Z = -12.3$, $p < 0.001$).

With advances in technology, in terms of hearing aid architecture, hearing aid prescription algorithms as well as digital processing techniques, issues related to gain have been largely reduced. Focus has shifted more towards better sound quality- especially so in adverse listening scenarios. Hearing aids that feature algorithms that can combine adaptive directionality and better digital noise reduction features are more highly sought after which could reflect a noisier society in general[8] and a greater need for communication in groups. A shift towards better speech quality in hearing aids is also reflected in the desire for better perception of their own voice. Better venting and AI-based modulation of hearing aid output to avoid hearing aid acoustics-induced distortion of one's voice help in this scenario[3], [9].

4. CONCLUSION

The findings of this study highlight several key trends in hearing aid usage and preferences over the past decade. Older adults (60-80 years) and children younger than 10 years are in greater need of amplification, and early intervention would be beneficial. A significant gender disparity was observed, with males being substantially more likely to procure hearing aids than females. This underscores the need for targeted awareness programs to encourage greater participation from women in addressing hearing loss-related quality of life issues. There was a marked shift in hearing aid preferences with a doubling in the adoption of RIC aids. This trend reflects a growing preference for more natural acoustics and reduced occlusion effects offered by RIC devices. Finally, user concerns have shifted from amplification / gain-based concerns to speech-quality focused issues, as reflected in more frequent speech in noise and own voice perception issues. Consequently, hearing aids with advanced noise reduction algorithms, such as adaptive directionality and differential own-voice processing were more frequently preferred. These findings suggest that better acoustics and AI-driven adaptive processing should be increasingly prioritized in hearing aid research.

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Noise abatement strategies for traffic noise : Global and indian perspectives

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ABSTRACT

Traffic noise significantly impacts urban acoustic climates globally due to the growth in vehicular population. Numerous studies have aimed to mitigate traffic noise, with traffic noise modeling serving as an initial step to predict noise levels, identify influencing factors, and locate hotspots using Geographic Information Systems (GIS). This study reviews various traffic noise models and their roles in predicting noise levels and identifying key factors. It explores effective abatement measures focusing on the source, propagation, and receiver stages. The study also highlights the challenges in implementing these measures and proposes a strategic framework for mitigating traffic noise. The findings suggest that an integrated approach which is a combination of regulatory policies, technological advancements, and urban planning is essential to achieve significant noise reduction and improve the quality of life in urban areas.

1. INTRODUCTION

1.1 Noise pollution

Noise is ranked as the second most significant environmental stressor, costing societies between 0.2-2% of their gross domestic product (GDP) (WHO, 2018). It can lead to various adverse health effects, including annoyance[1,2] cardiovascular diseases[3] and elevated blood pressure[4] and a multitude of physiological and psychological related health issues[5]. These health problems diminish the quality of life and can, in some cases, result in mortality[6,7]. Noise is quantified in decibels (dB) using the A-weighting scale, which accounts for the frequency range of the human ear (20 Hz to 20 kHz)[8]. Noise levels vary depending on time, source, and location. The equivalent noise level (L_{eq}) is a measure that represents the constant sound level containing the same acoustic energy as the fluctuating sound over a specified period[9]. L_{eq} is a commonly used parameter in noise studies and has a strong correlation with subjective noise perception[10,11]. On the A-weighting scale, L_{eq} is indicated as L_{Aeq} and can be determined using the following equation[12].

$$L_{Aeq} = 10 \log\left(\frac{1}{T}\sum_{t=1}^{T} 10^{\frac{L_{Aeq.1s}(t)}{10}}\right) \tag{1}$$

Here, $L_{Asq.1s}$ signifies A-weighted equivalent noise levels measured at 1-second intervals, with *'T'* representing the total measurement duration. In addition, some researchers have employed L_n, indicating the n^{th} percentile noise level in a particular duration. The value of *n* is generally 10, 50 and 90, which are depicted as L_{A10}, L_{A50} and L_{A90}, respectively. The L_{A10}, L_{A50} and L_{A90}, depict the particular noise level over which the noise level exceeded 10%, 50% and 90% of the time on an A-weighted scale[12].

Regulatory agencies have established standards to limit ambient noise levels. In India, the Central Pollution Control Board (CPCB) in New Delhi sets the noise standards. According to CPCB, permissible noise levels during the daytime should not exceed 50 dBA in silence zones, 55 dBA in residential zones, 65 dBA in commercial zones, and 75 dBA in industrial zones. Each of these limits is relaxed by 5 dBA during nighttime. Silence zones are defined as areas within 100 meters of hospitals, educational institutions, and courts. Daytime is designated as the period from 6 am to 10 pm (16 hours), while nighttime is from 10 pm to 6 am (8 hours)[13]. On a global scale, the World Health Organization (WHO) recommends that ambient noise levels should not exceed 55 dBA during the day and 45 dBA at night[14].

1.2 Urban traffic noise pollution

Ambient noise levels are being violated in urban areas due to rapid growth in population and economic development. According to a United Nations (UN) report, the world's urban population accounted for 55% of the world's population in 2018 (4.2 billion out of 7.6 billion people), and it is expected to exceed 68% by 2050[15]. Almost all city dwellers are expected to get exposed to traffic noise at least once a day, and most of them are expected to experience high traffic noise levels for a longer duration[16]. Among the various sources of noise (i.e., road traffic, railway, aircraft, industry, community, construction activities, loudspeakers), road traffic is the most pervasive and contributes more than 70-80% to total urban noise pollution[17-19]. The road traffic noise level is continuously increasing in cities due to highly congested road networks and significantly higher vehicular population in cities compared to rural areas. For instance, Thakre *et al.* (2020) demonstrate that traffic noise level has increased by 5-6 dBA on roads in Nagpur, India, from 2012 to 2019 due to vehicular growth[20]. Thus, it is negatively impacting the health and reducing the quality of life of dwellers in cities, especially in the vicinity of road networks[21-23].

The traffic noise levels in cities in developing countries like India are expected to worsen due to poor policies and inadequate mitigation strategies. These cities are often poorly organized and lack the facilities found in developed countries[24]. The urban infrastructure, city planning, and control measures in developing countries like India differ significantly from those in economically developed countries. In terms of road transportation, Indian cities typically exhibit highly heterogeneous traffic flow characteristics, inadequate traffic flow control measures, a lack of organized public transport systems, and a high reliance on personalized vehicles (i.e., two-wheelers and shared three-wheelers) for daily commuting. Additionally, poor vehicle maintenance, complex driving styles, and frequent honking are very common in mid-sized Indian cities. These factors result in worse traffic noise levels in Indian cities compared to economically developed ones[25]. Furthermore, urban road networks in cities have a larger number of intersections compared to rural areas. Intersections are generally noisier than other parts of road networks, which elevates the overall noise levels in the city. Consequently, city dwellers, especially those residing near road networks, face severe threats from traffic noise pollution[26].

1.3 Research motivation and contributions

Traffic noise is a significant factor contributing to poor urban acoustical environments globally and in India. Therefore, it is crucial to propose effective measures to control traffic noise levels. Traffic noise modeling is recognized as the initial step towards mitigating and managing this issue. These models help identify various factors influencing traffic noise and predict noise levels along urban road networks. Based on these predictions and the nature of the influencing factors, strategies can be developed and implemented to reduce traffic noise.

The literature indicates that various innovative measures and practices have been adopted worldwide to control traffic noise in different contexts. However, challenges remain in proposing and implementing effective abatement measures. This study aims to review existing literature on traffic noise to investigate the factors influencing traffic noise, the prediction models used globally and in India, and the control measures and strategies that have been adopted. Finally, the study will discuss the challenges in applying different strategies to control traffic noise. Thus, the present study contributes to the traffic noise literature by discussing the factors influencing traffic noise, examining traffic noise prediction models, highlighting innovative measures and policies adopted, and addressing the challenges in implementing these abatement strategies.

2. FACTORS RESPONSIBLE FOR AFFECTING TRAFFIC NOISE

Road traffic is the most invasive source of noise pollution near roadways[27]. Noise emitted from vehicles propagates through the atmosphere to reach the receiver, influenced by various attributes at the source, propagation, and receiver stages[28,29]. These attributes are categorized into factors such as traffic factors, road geometry, climate conditions, and the built environment[30-34]. Traffic factors include traffic volume, composition, speed, honking, and the percentage of heavy vehicles[20], [35-37]. Road geometry factors encompass carriageway width, lane number, road surface, median width, pavement type, road gradient, and distances of the sound level meter from various reference points, such as the centerline of the carriageway, buildings, signal stop lines, and barriers[25], [38-41]. Climate conditions consider relative humidity, temperature, and wind velocity[42,43]. Built environment factors include building height, density, unauthorized street parking, land use, vehicle ownership and population density[25], [31], [44,45].

However, the impact of these variables is not uniform and varies with context. For instance, traffic volume is positively correlated with traffic noise levels, causing a 3 dBA increase with higher traffic volume[46]. Speed positively impacts traffic noise in uninterrupted flow conditions but negatively in interrupted flow conditions[34], [47,48]. This illustrates that many attributes can affect traffic noise levels in different contexts. Additionally, context-specific attributes can significantly impact traffic noise levels at particular locations. For example, honking is a notable factor in heterogeneous Indian traffic conditions[32], [49,50]. Kalaiselvi and Ramachandraiah (2016) found that honking can increase noise levels by 0.5 to 13 dBA[51]. Hamad *et al.* (2017) highlighted the effect of temperature in the hot regions of Sharjah, United Arab Emirates (UAE)[42]. Researchers can use this foundational knowledge to include context-specific attributes in their analyses of traffic noise levels in cities.

3. TRAFFIC NOISE PREDICTION MODEL

Traffic noise prediction is essential for developing effective abatement strategies. Various models have been developed to predict noise levels caused by road traffic, involving relationships between influencing attributes and traffic noise levels. The earliest known model appeared in the 1952 Handbook of Acoustic Noise Control, utilizing traffic volume and speed as independent variables and traffic L50 as the dependent attribute[29]. There are two main types of traffic noise models: conventional traffic noise prediction models and locally calibrated models.

3.1 Conventional traffic noise prediction modelling approach

Conventional models, created primarily in developed countries, include various adjustments to enhance their applicability across different contexts. Notable conventional models include the Federal Highway Administration (FHWA) Traffic Noise Model from the USA[52], the Calculation of Road Traffic Noise (CORTN) model from the United Kingdom[53], the Richtlinien für den Lärmschutz an Straben (RLS 90) model from Germany[33], the Acoustical Society of Japan-Road Traffic Noise model (ASJ-RTN-Japan) from Japan[54], and the Common Noise Assessment Methods (CNOSSOS-EU) from the European Union[55].

These models are designed for homogeneous and uniform traffic flow conditions typically found in developed countries. However, vehicle characteristics, driving behavior, and environmental conditions vary significantly across countries. As a result, the prediction accuracy of conventional models decreases when directly applied to other countries with different traffic flow conditions[56,57]. Researchers have modified these models to suit different contexts[51], [58,59]. For instance, Quiñones-Bolaños *et al.* (2016) modified the CORTN model to predict traffic noise levels at intersections, and (Shukla *et al.* (2009) included additional vehicle categories in the FHWA model for highway traffic noise analysis. Modifying conventional models is complex and labor-intensive, and they often do not account for specific local phenomena, such as frequent honking in some regions. Consequently, locally calibrated models are developed to improve prediction accuracy[60,61].

3.2 Locally calibrated traffic noise prediction models

Locally calibrated models are constructed based on field data and validated with data from similar contexts. These models are tailored to specific locations and can be applied to similar contexts without modifications. Various methodological approaches are used to develop these models, including empirical, soft computing, mathematical, simulation, and structural equation modelling. Empirical approaches often involve statistical regression to establish linear relationships between influencing variables and traffic noise levels. Various studies have been conducted globally to develop traffic noise models in varying contexts utilizing the regression approach due to its simplicity and interpretability[62-66]. Soft computing techniques have gained popularity with advancements in artificial intelligence and machine learning, offering high prediction accuracy. These techniques include artificial neural networks, genetic algorithms, machine learning with geoinformatics, land use regression, adaptive neuro-fuzzy inference systems, data mining regression trees, support vector machines and Gaussian processes[67-69]. While these techniques excel at predicting traffic noise levels, they often lack transparency in estimating the effect of specific attributes due to their black-box nature.

Mathematical approaches consider the effects of reflection, refraction, propagation, and absorption, using methods like the inverse square law and integral Fourier transforms to estimate traffic noise[70,71]. Simulation techniques have recently been used to estimate timewise variations in traffic noise levels by considering different traffic flow characteristics (e.g., speed, position, acceleration) over time for each vehicle category[72,73]. In the simulation approach, traffic flow data for different scenarios are first extracted using software such as AVENUE, VISSIM, and Paramics. These conditions are then coupled with existing models like ASJ-RTN-1998 and CNOSSOS[73-75]. Structural equation modeling (SEM) has recently been introduced for analyzing and estimating traffic noise for urban traffic flow conditions and intersections. Recently researchers have used SEM-based technique to estimate traffic noise levels, considering the interrelationships between influencing variables and with traffic noise levels[25,35].

While various models have been developed worldwide using different influencing variables and methodological approaches, literature suggests that locally calibrated models, despite being site-specific, are generally more accurate than conventional models[42,76].

3.3 Traffic noise modelling in Indian scenario

Since independence, traffic noise in India has increased exponentially with the country's development and growth in vehicle ownership. Recent studies indicate that Indian cities have exceeded their environmental noise capacity, especially near road networks[19]. Thus, developing traffic noise models suited to Indian conditions is crucial for proposing effective solutions.

Existing models from developed countries are often unsuitable for Indian traffic conditions and may yield inaccurate results[60,77]. The first traffic noise prediction model for Indian conditions was developed by Seshagiri Rao *et al.* (1989) to predict L_{Aeq} based on traffic density in Vishakhapatnam[78]. Rao & Rao (1991) later developed another model to calculate L_{10}, considering traffic volume as the input parameter for Vishakhapatnam[79]. Subsequently, various studies have focused on developing traffic noise prediction models for different contexts, such as urban roads[32,80], intersections[61,63,81], highways[82,83], minor roads[84], mid-blocks[60] and bus rapid transit systems[17,85].

4. TRAFFIC NOISE ABATEMENT MEASURES

Traffic noise can be controlled at three stages: the source, propagation, and receiver stages. Primarily, measures are adopted to minimize noise emission levels at the source by implementing strategies such as changes in traffic flow, vehicular characteristics, road geometry, tire and pavement properties, and more[86]. For instance, the Central Pollution Control Board (CPCB) in India has set noise limit standards to control noise emissions from motorized vehicles during manufacturing, capping them at 75-80 dBA[87]. Horn noise should not exceed 112 dBA for all vehicle types. In 2013, the Supreme Court of India banned pressure horns, multiple sound-emitting horns, and musical horns in vehicles. The Ministry of Road Transport and Highways (MoRTH) proposed penalties for vehicle owners using multi-toned and air horns and issued challans for fitting pressure horns. In Delhi, honking has been banned within 100 meters of silence zones. In 2017, the Delhi Police fined over ten thousand people for noise-related offenses[8]. In Delhi, studies indicate that traffic noise, especially horn noise, occurs predominantly in the 2.5-4 kHz frequency range, suggesting the need for higher sound insulation and control of the coincidence dip in sound transmission loss[28].

Various projects in Western countries have aimed to control traffic noise pollution, such as HEAVEN (Healthier Environment through Abatement of Vehicle Emission and Noise), SilVia (Sustainable Road Surfaces for Traffic Noise Control), CALM (Community Noise Research Strategy Plan), ROTRANOMO (Development of a Microscopic Road Traffic Noise Model for the Assessment of Noise Reduction Measures), and FOREVER (Future Operational Impacts of Electric Vehicles on National European Roads)[28,86]. These studies report that effective traffic flow control, low-noise pavement, low-noise tires, barriers, and vegetation are feasible solutions to control traffic noise.

The HEAVEN project found that banning heavy vehicles and imposing speed restrictions within 30 km/h in cities can reduce traffic noise levels by 5.7 dBA. A 20% reduction in traffic volume can result in a 1 dB noise reduction, provided other factors such as speed and composition remain unchanged. Traffic calming measures can cause up to a 4 dB L_{Aeq} reduction and a 7 dB L_A max reduction depending on traffic congestion, speed, and road layout[8]. Reducing vehicle speed by 10 km/h can achieve a 2-3 dBA noise reduction[88]. Adjusting traffic lights according to vehicle speed to favor rolling near the speed limit can reduce noise levels, and optimizing traffic fluidity through traffic light control can gain up to 2 dB(A). Converting intersections regulated by traffic lights or stops into roundabouts can reduce noise by 1-4 dB(A)[8,89]. The FOREVER project indicates that electric vehicles are effective in reducing propulsion noise, potentially lowering overall noise emissions by 2.7 dBA for light vehicles and 10 dBA for heavy vehicles at 30 km/h compared to diesel engine vehicles. However, this difference decreases at higher speeds due to the dominance of rolling noise, remaining only 0.4 dBA at 110 km/h for light vehicles and 1.5 dBA at 90 km/h for heavy vehicles[86]. Retrospective literature suggests that tire width, hardness, tread patterns, groove depth, and road surface are crucial factors affecting rolling noise. Low-noise tires can reduce noise by 3-5 dBA[86]. Low-noise pavements, such as bituminous pavement, Poroelastic Road Surface (PERS), and Enhanced Porosity Concrete (EPC), can reduce rolling noise by 3-5 dBA, 7-9 dBA, and 10 dBA, respectively[90].

Additionally, barriers can effectively reduce traffic noise. They work by blocking the line of sight, creating a sound shadow[88]. Depending on the height and placement, barriers can reduce noise levels by 7-10 dBA[90]. Green spaces can also act as natural barriers; for example, 10-12-meter high trees can reduce traffic noise[91]. The Federal Highway Administration (FHWA) demonstrated that dense vegetation of about 61 meters (200 feet) could achieve almost a 10 dBA noise reduction. Someya *et al.* (2022) observed a 4.1 dBA reduction along the Bus Rapid Transit System (BRTS) corridor with vegetation. Buffer zones, increasing the distance between the noise source and receiver, and considering receiver orientation, height, and location are also crucial for reducing potential traffic noise problems[90].

5. 5. DISCUSSIONS AND CONCLUSIONS

A road traffic noise model is essential for accurate noise predictions and identifying influencing factors. Such a model can be integrated with Geographic Information Systems (GIS) to identify hotspots where L_{Aeq} levels exceed threshold values. Implementing the most practical and economical options among various alternatives can help control traffic noise at these hotspots. Efficient traffic management is vital for combating high ambient noise levels. In India, honking significantly contributes to traffic noise, adding 4-12 dBA to noise levels near urban roads[51]. Measures such as restricting horn use, reducing speed limits, timing traffic lights to ensure smooth traffic flow, encouraging smooth driving to avoid frequent acceleration and deceleration, and prohibiting heavy vehicles on certain roads can effectively minimize traffic noise.

Land use planning, building density, orientation, and facades also play important roles in controlling traffic noise. While these solutions can significantly reduce traffic noise levels, there are challenges in implementing them. For instance, identifying individuals honking in traffic stream is difficult. Noise barrier walls, though effective, are expensive and require breaking the line of sight to work properly, which is not always feasible at intersections or driveways. Acquiring land for buffer zones is impractical due to excessive land use. Roundabouts can reduce congestion and ensure smooth traffic flow but are challenging to implement due to space constraints and the need for appropriate deflection around the central island. Vegetation acts as a natural barrier but takes many years to grow and is less effective at higher tree heights.

European noise abatement programs offer valuable insights for devising action plans and strategies suitable for Indian contexts. For example, the Dutch noise innovation program, with a budget of 50 million Euros, aims to reduce the number of houses exposed to noise levels greater than 70 dB(A) by 100%, greater than 65 dB(A) by 90%, and greater than 60 dB(A) by 50% by 2030. The European Parliament and Council's Directive 2002/49/EC, known as the Environmental Noise Directive (END), aims to create "strategic noise maps" for major roads through noise monitoring, informing the public about their noise exposure levels and its effects on health. This approach helps garner public support for noise abatement strategies[8].

Electric vehicles, especially on low-noise pavement surfaces, can be an effective solution. By integrating advanced traffic noise models with GIS, implementing effective traffic management strategies, and adopting new technologies, we can significantly mitigate the impact of traffic noise and improve the urban acoustical environment. New technologies and improvements, such as quieter engines, low-noise tires for vehicles, and low-noise brake blocks for trains, are important contributions to reducing noise levels from all transportation sources. An inventory of noise control measures focused on the source, path, and receiver is essential to achieve desired noise reduction targets.

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Effect of voice changing software on original voice : A comparative study for the detection of spoofed voice signals

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ABSTRACT

With the advent of technology, certain advancements proved to be a boon for the mankind. However, some of them instilled a sense of mischief in the minds of the perpetrators. Voice spoofing is one of them. In general, spoofing can be defined as an attack involving the use of fake biometrics for a valid person. For voice, the fraudsters make use of voice conversion or imitation, impersonation, advanced speech synthesis, and recorded replay to intimidate a victim or attempt thefts or scams. A number of software and mobile applications are available which allow the user to change their voice into a robot or to imitate the voice of the opposite sex. In the present work, we studied various changes which occur when the original voice of a female speaker is converted into the voice of a male, a child and a robot using a voice spoof application filter. Furthermore, an attempt was made to differentiate between original voice signals and synthetic voice signals using various analytical methods and the factors / parameters which get modified when such filters are applied to original voice. Thus, this study can be foreseen as a boon to the forensic community as it will aid the forensic investigators in offenses which involve the use of spoofed voice signals.

1. INTRODUCTION

The technological advancements yielded using deep learning methods have put forth numerous tools which are based on artificial intelligence (AI). It ends up making the technology easy to manipulate. The artificial / filtered signals so produced, are highly realistic and convincing. Voice changing software and applications are easily accessible to the common man these days. This has lead to a sharp rise in the number of offenses which involve the use of spoofed voice / signals, for example intimidation, spreading fake news, making ransom calls, breach of security systems, etc., by either impersonating a real or imaginary individual, voice conversion or by synthetic speech synthesis[1].

The detection of synthesized voice is emerging as a consequential challenge. It is because of the easy availability and open access to a wide variety of spoofed signal generation methods / tools. Synthetic speech can be procured using different ways like cut-paste techniques namely concatenation of the voice signal waves[2], which are mostly available in the form of an open source toolkit. Another technique involves the exploitation of vocoders[3]. Lately, myriad of methods utilizing the convolutional neural networks (CNNs) have been brought forward for the purpose of synthesizing audio signals[4]. All these procedures yield exceptionally naturalistic outcomes, so much so, that disambiguating them from original sound signals is an arduous task.

In this study, we have made an attempt to differentiate original voice signals from filtered / synthetic voice signals. The organization of the paper is as follows; first, we enlist the wide variety of methods which are commonly used for the generation of spoofed signals. This section will be followed by an extensive literature review which will shed light on the various methods which have been used in the past for the detection of these signals. Moving further, there are some informative bullet points which tell us about the parameters that change with the change of nature of speaker (a child, a male, a female and a robot). It is followed by the list of materials and methods used in the present study. Next in line are the detailed discussions and results of the work. It is then concluded with a brief paragraph explaining the outcomes and the scope of this study.

1.1 Generation of fake/imposter speech

There is a wide variety of methods which can easily be employed for the purpose of generating synthetic speech signals. Each one of these methods can be distinguished based on their own individual characteristics. Considering the algorithms of fake-speech production, text-to-speech (TTS) synthesis, HMM (hidden Markov model) -based speech synthesis system, restrictive Boltzmann machine (RBM), parametric TTS synthesis algorithms, artificial neural networks (NNs) like deep neural networks (DNN), multi-distribution deep belief network (DBN), deep mixture density network (DMDN), convolutional neural networks (CNN), bidirectional recurrent neural networks (BRNN), deep bidirectional long short-term memory (DBLSTM), end-to-end speech synthesis methods like Tacotron, WaveNet, etc., are some of the numerous procedures used in the past for the conversion of original speech signals into the synthetic signals[5,6].

Considering the basis of these voice-changing algorithms, most of the models analyze and extract certain acoustic features from the original voice sample and then synthesize fake signals which have similar characteristics. Some of them work on smoothing the auditory features or they modify several parameters of the voice signals like pitch, amplitude, tone of the voice, etc. Another method includes the addition of distortion to the user's voice, or a combination of both. Pitch plays an essential role from changing a male voice into female voice, and vice versa. Hence, these algorithms yield triumphant results in imitating real individual or concocting the signals of an imaginary creature.

1.2 Detection of fake speech

Detecting whether a speech signal is a real or an algorithm generated signal is not an easy task. Keeping in mind, the wide range of tools available for the generation of synthetic speech, it is quite difficult to develop a general forensic model which is able to explain all the pre-existing models for generation of synthetic speech. Furthermore, considering the escalating number of discoveries of deep learning solutions and the fact that more novel and improved models for production of synthetic signals are being presented, it makes it quite formidable to keep pace with the pre-existing techniques for the production of fake speech signals.

In spite of all the above-mentioned hurdles, various forensic scientists have put forward multiple analytical techniques for the detection of synthetic signals in order to counter the mushrooming misuse of synthetically produced voice recordings. Conventional methods of detection were focused on the extraction of certain meaningful features from the speech samples, which further aided in the discrimination of fake speech signals from original signals. It was eventually manifested that complex classifiers were overshadowed by effective and spoof-aware features. In another study, M. Todisco *et al.* used constant-Q cepstral coefficients (CQCC) as a countermeasure for automatic speaker verification. X. Xiao *et al.* worked on detection of spoofed speech using frequency-time analysis, high dimensional magnitude features like log magnitude spectrum and phase features like group delay[7-9]. Later on, M.

Sahidullah *et al.* drew a comparison of various features for synthetic speech detection. In this study, sub-band analysis was used[5].

Further advancements in detection methods included deep learning approaches. Neural Networks were put forward both for classification as well as feature learning steps. For an instance, in year 2017, Hansen *et al.* used deep-learning methods for anti-spoofing by authenticating a speaker[6]. They utilized Convolutional Neural Networks and Recurrent Neural Networks for feature/characteristic learning and capturing long-term dependencies which were further used as classifiers. In 2019, Bestagini et al. developed a synthetic speech detector using the similar approach. They worked with the help of frequency time depiction of the voice signals recorded using simplified CNN architecture[10]. End-to-end strategies were also put forward for sensing spoofed signals[11].

Various other algorithms focusing either on analysis of hand-crafted features or data-driven characteristics have previously been suggested for speaker verification anti-spoofing[1,5,6]. In 2015, M. Sahidullah *et al.* attempted to compare the various features which could possibly be used for synthetic speech detection. Later in 2017, Zhang and Hansen investigated the machine-learning features for the verification of spoofed speech signals. In 2019, another method was proposed by H. Farid et al. is in their study, "Detecting AI-synthesized speech using bi-spectral analysis" for the detection of audio deep-fakes[12]. Very recently, Borrelli *et al.* attempted to develop a synthetic speech signal detector which carries out the detection of synthetic voice signals with the help of open-set or closed-set prediction traces[1].

1.3. Distinguishing different types of voices (Male, Female, Child & Robotic): Multiple factors like intensity (loudness) and frequency (pitch) help in the process of distinguishing a child's voice from the voice of an adult. These differences may exist due to the variations in the anatomical as well as morphological features of the vocal-tract, varying degree of articulatory control and the ability to control the supra-segmental aspects such as fluctuating levels of stress and intonation. These aspects are known to induce major differences in speech. Some of the factors which vary in the speech signals of four different groups of people namely children, males, females and robots are given below.

a. In case of children:

- Elevated fundamental and formant frequency values.
- Considerable variations in spectra as well as the speaking rate.
- Steady average speaking rate.
- Higher degree of spontaneity.

b. In case of males:

- Voice is usually lower-pitched possibly due to the presence of larger folds.
- Rough articulation.
- Higher intonation that is use of full pitch range during speech production.
- Varying the range of volume instead of pitch during a conversation (usually used for increasing the emphasis).
- Low frequency pitch and therefore, fewer frequency components.
- Lower Speech Interference Levels (SIL) that is fewer octave bands.

c. In case of females:

- High pitched voice.
- Gentler articulation.
- Variation of pitch range instead of volume during speech.
- More frequency components compared to men.
- Higher Speech Interference Levels (SIL) - females usually speak one octave higher than men.

In case of robotic voice effects:

- It is produced by extracting some features from the original voice and modifying (usually increasing) their frequency and then its addition into the original file.
- The frequency increases slightly.
- The pitch of a sound signal also rises with the rise in frequency.
- These can be produced using Vocoders, Sonovox, Talk box, Ring modulator, software named Vocaloid, Comb filters, etc.

2. MATERIAL AND METHODS

In this study, voice samples of ten (10) female speakers (marked as S1-S10) were recorded using a voice changing mobile phone application named *"Voice FX"*. The voice sample of each speaker was taken / recorded in natural (original) voice that is without any filter or change, and then filters namely male, child and robotic were applied to the original voice samples and saved, that is, each speaker having four samples. All the files were saved in .mp3 *(MPEG)* format. Further, for the purpose of analysis, the recorded samples were converted into .wav format using software *VLC media player ver*.3.0.14.

The following procedure sequence was used for the analysis of these samples. At first, critical listening was performed along with the simultaneous study of wave morphology for all the samples in a sound proof speech lab at *Central Forensic Science Laboratory, Chandigarh*. It was done using software *Goldwave* ver.4.21. Further, the values of *Wideband (WB), Narrowband (NB)* and *Linear predictive coding (LPC)* were noted down. It was carried out using the software *Multispeech* ver.2.7. The presence of variations was observed and recorded. Apart from the variations in aforesaid parameters, the conversion of voiced signals to un-voiced signals was also observed in the spectra. This was one of the many significant outcomes of this experiment. Not only this, noteworthy variations in harmonics was also noticed. All these findings were recorded and analysis was carried forward. Loss of frequency / smoothening of sample could be observed from these spectra. However, to prove the same, additional analysis of frequency values was done using software Tony ver.2.1.1. Spectrums were also plotted using software *Audacity* ver.2.0, which showed visible differences. Changes in the background noise along with the phase diagrams were plotted using software *Adobe Audition* ver.1.0. After the spectral analysis, hex analysis was also carried out for all the samples using software *HHD Software Hex Editor* Ver.4.1.0.31 and *FlexHEX* ver.2.71. It was done both for the .mp3 as well as .wav files. Metadata analysis was also performed in order to find some exclusivity which may demonstrate a vivid proof of spoofed signals. It was done using software *Mediatab* ver.1.4.1 and *MediaInfo* ver.21.03.

3. RESULTS AND DISCUSSIONS

3.1 Critical Listening

Evaluation of both foreground and background sounds was done with the help of careful auditory examination. Significant variations in noise floor were observed. It was quite high in case of sample with no effect. However, in case of filtered samples, it was smoothed down. Moreover, based on careful examination of filtered samples, it could clearly be discovered that the signals so heard had certain shortcomings like absence of intonation, the change of pitch and the modified frequency were not realistic enough so that we can say it could imitate the voice of a real male or a real child. Similar finding was there in case of the robotic filter.

3.2 Spectrographic/Waveform analysis

During analysis, it was observed that in case of a child and a original sample, there was an average formant frequency difference (WB & LPC readings) of around a 800-1000 Hz and a frequency difference of 70-80Hz in the pitch values (NB reading). However, in case of a male (filtered), the formant frequency

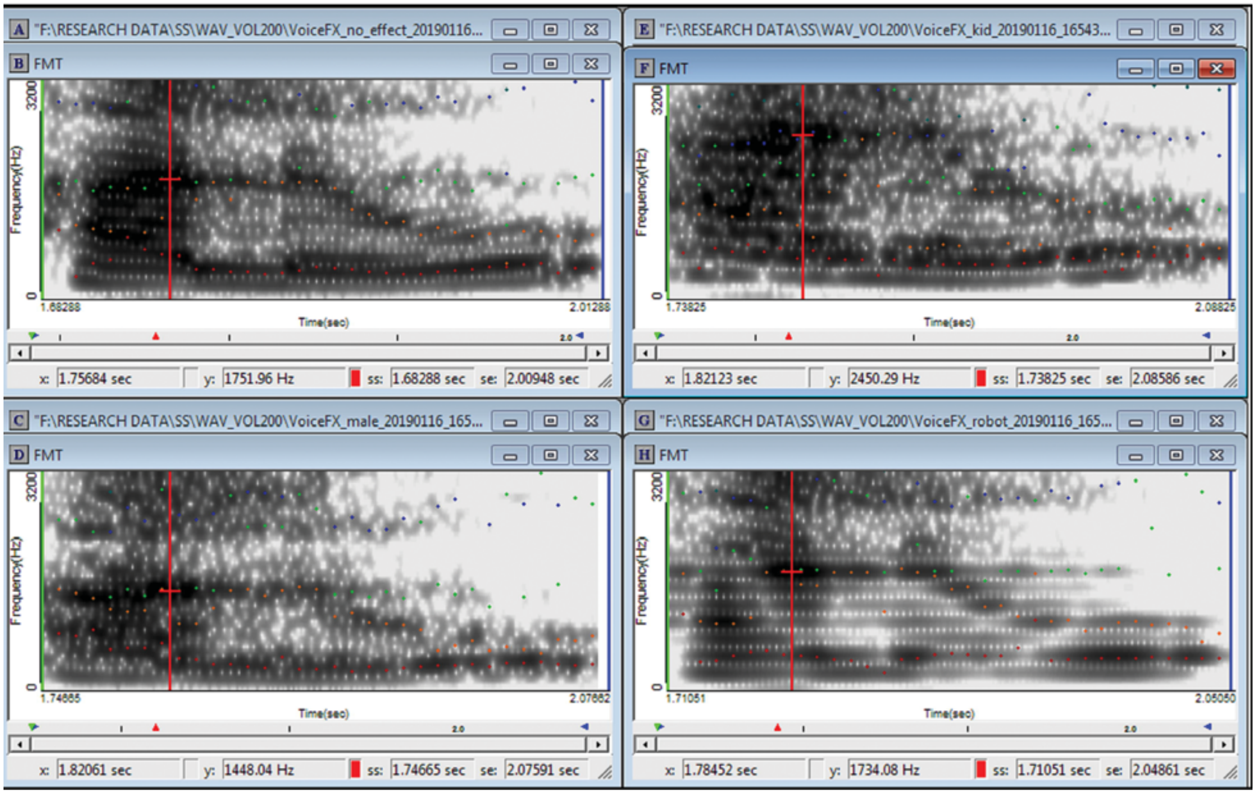


Fig. 1. Comparison based on Wideband (WB) readings

difference decreased by nearly 300-400 Hz on average and the difference in the value of pitch also declined and touched 40Hz. In case of the robotic voice, the WB and LPC values approached similar frequencies varying only by 20-40 Hz. Similarly, the readings of pitch value were similar. The highest pitch value was observed in case of child followed by the female voice, which was followed by the male voice and the lowest was in case of the robotic voice signals. A similar pattern was observed in all the respective sample readings. Figure 1 and Table 1 clearly shows the results.

Table 1. WB, NB and LPC Values obtained during Spectrographic Analysis.

ID	WB reading				NB reading				LPC			
	Original	Child	Male	Rob	Original	Child	Male	Rob	Original	Child	Male	Rob
S1	2117.44	2995.76	1815.88	2147.48	282	282	193	125	2108.91	2986.93	1755.97	2114.18
S2	2243.15	3027.07	1889.92	2214.71	315	324	275	245	2296.03	3017.10	1896.45	2210.05
S3	2426.26	3150.00	1966.36	2406.28	256	334	290	268	2412.35	3162.93	1981.74	2336.19
S4	2014.31	2535.37	1756.36	2768.18	256	315	208	315	2007.76	2574.60	1725.87	2886.18
S5	2563.44	3626.34	2080.58	2558.18	306	239	282	275	2548.90	3645.67	2167.37	2548.11
S6	1739.58	2765.85	1450.91	1794.21	290	200	245	256	2098.80	2760.65	1705.80	2099.04
S7	2029.52	2873.41	1648.96	2023.64	225	306	193	245	1992.59	2851.16	1595.43	1902.25
S8	1520.69	2412.49	1438.04	1527.27	256	183	256	256	1648.69	2358.37	1449.93	1604.55
S9	2645.45	3538.15	2215.64	2659.80	238	326	210	145	2638.12	3502.62	2202.35	2635.18
S10	1836.58	2854.12	1564.04	1845.64	312	262	275	245	1824.96	2812.40	1559.42	1836.00

3.3 Voiced/unvoiced signals (V/UV)

On analysis, it has been observed that the use of filters namely male, kid and robot lead to the conversion of voiced signals to unvoiced signals and the maximum was found in case of the robotic filter as shown in figure 2 given below.

Sample No.	Time (sec)	Pitch (Hz)
1	1.60925	Unvoiced
2	1.63425	Unvoiced
3	1.65925	Unvoiced
4	1.68425	Unvoiced
5	1.70925	Unvoiced
6	1.73425	246.15
7	1.75925	Unvoiced
8	1.78425	Unvoiced
9	1.80925	242.42
10	1.83425	242.42
11	1.85925	246.15
12	1.88425	Unvoiced
13	1.90925	Unvoiced
14	1.93425	Unvoiced
15	1.95925	246.15
16	1.98425	246.15
17	2.00925	246.15
18	2.03425	Unvoiced

Voiced signals in case of original speech sample

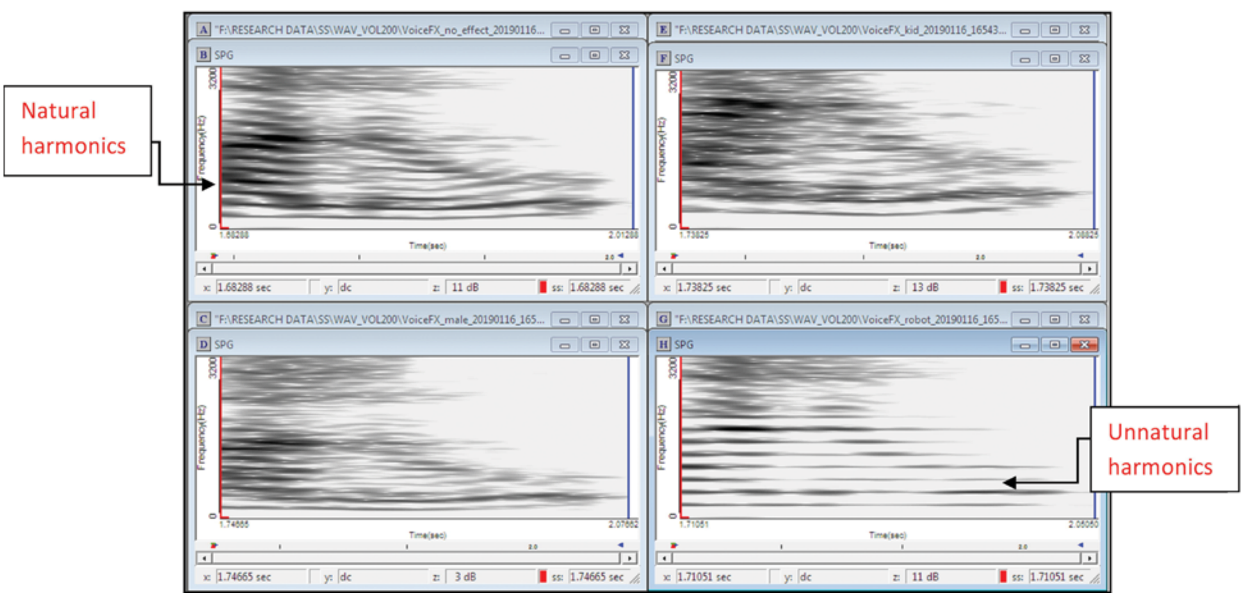
Sample No.	Time (sec)	Pitch (Hz)
1	3.99331	Unvoiced
2	4.01831	246.15
3	4.04331	246.15
4	4.06831	246.15
5	4.09331	246.15
6	4.11831	246.15
7	4.14331	Unvoiced
8	4.16831	Unvoiced
9	4.19331	Unvoiced
10	4.21831	Unvoiced
11	4.24331	Unvoiced
12	4.26831	Unvoiced
13	4.29331	Unvoiced
14	4.31831	Unvoiced
15	4.34331	Unvoiced
16	4.36831	Unvoiced
17	4.39331	Unvoiced
18	4.41831	Unvoiced

Unvoiced signal ratio increased in case of robotic voice (filtered)

Fig. 2. Comparison based on voiced and unvoiced signals.

3.4 Variations in harmonics

In case of harmonics, various modifications were observed in case of the robotic filter, wherein, the striations present in specific bands were erect / upright, non-continuous and very unnatural. On the contrary, in case of the original sample, the striated bands so formed are very natural and they depict the vibrations which actually take place when a voice signal is produced. It confirmed the alteration of pitch in the respective samples. Resultant spectra are demonstrated in figure 3.



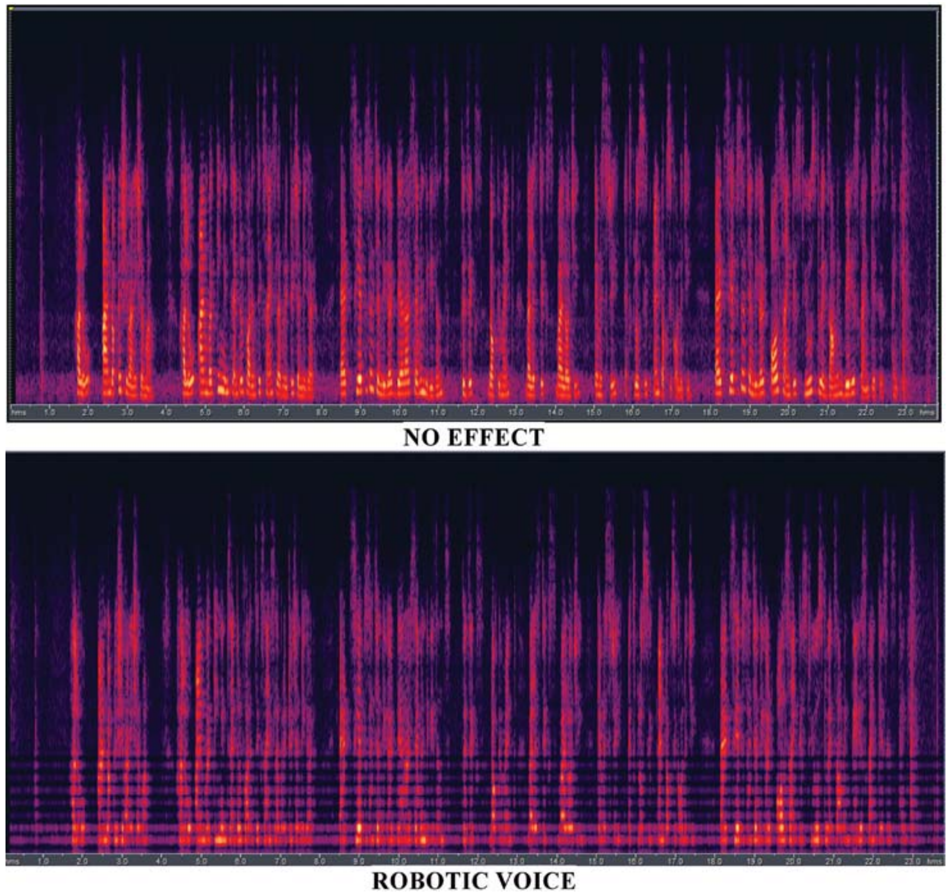


Fig. 3. Comparison based on harmonics.

3.5 Loss of frequency values

While recording the wideband frequency values, it could easily be observed that lesser number of formants were formed. It clearly meant that application of the filter lead to loss of frequency values. However, it was proved by the frequency analysis as shown in figure 4.

3.6 Spectral analysis

The spectra were plotted using Hamming window function for all the samples. As seen in figure 5, the maximum frequency range covered by the original sample that is female voice was as high as approximately 7300 Hz which is similar in case of the child's voice. Whereas the acoustic pressure was higher in case of the kid's voice as compared to the female voice. In case of the male voice, the frequency was the lowest of all and the acoustic pressure was highest among all other samples. A different trend of spectral pattern was observed in case of the robotic voice samples. The acoustic pressure was similar to that of a child but the frequency range cover was around 7000 Hz.

3.7 Changes in noise floor

Certain variations in the noise floor of original and filtered audio signals could be recognized during critical listening. On further analysis, it was found that in actual, the noise signals were smoothed down in case of filtered samples. Prior to that, loss of frequency was observed when the voice signals were converted from an original sample to the robot filtered voice. In support of this, when the signals were

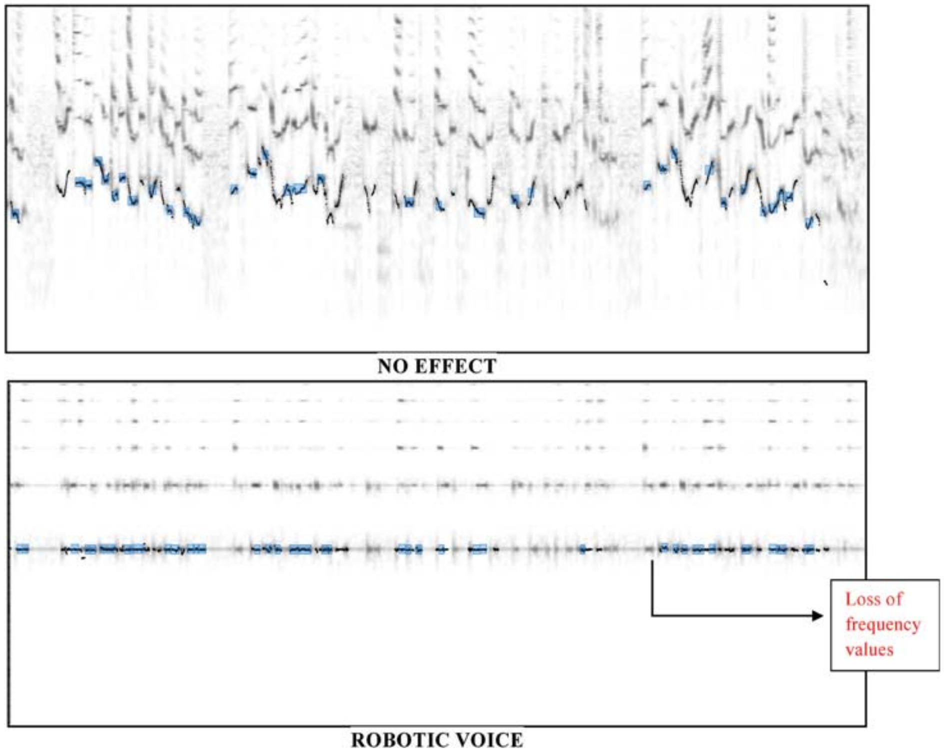


Fig. 4. Comparison based on frequency values. Abrupt changes can be vividly seen.

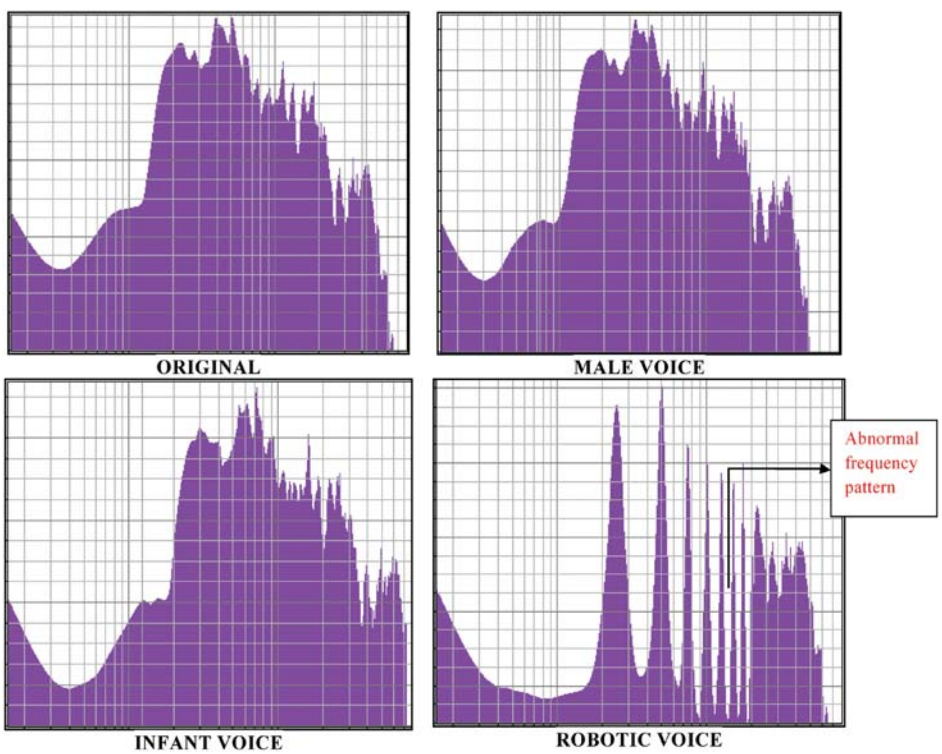


Fig. 5. Comparison based on visible spectral diagrams.

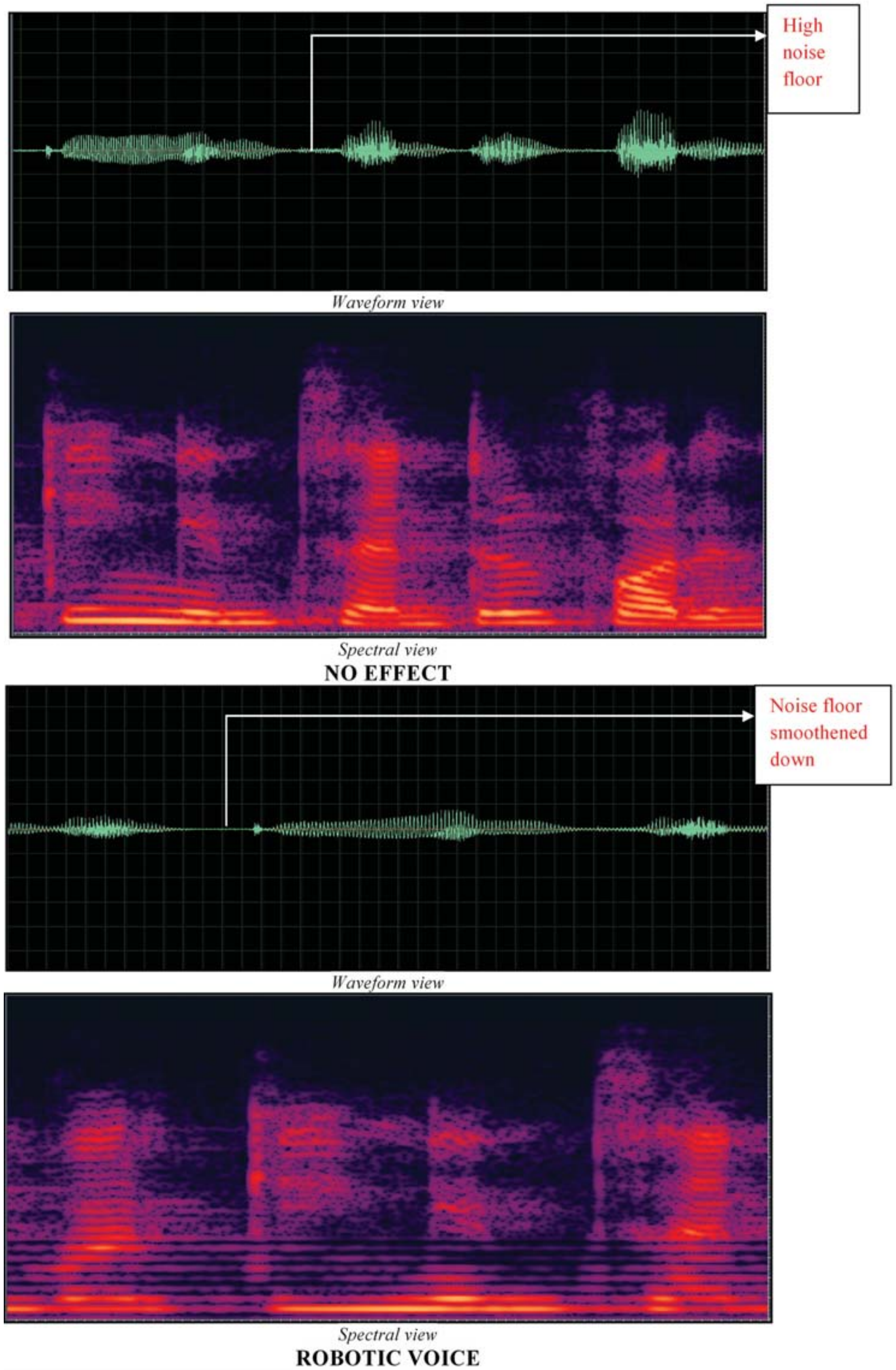


Fig. 6. Comparison based on changes in noise floor.

observed, it could be vividly seen in figure 6 that the background noise also decreases as the sample is smoothened/features are removed from it by the application's algorithm in order to make it sound like the voice of the robot.

3.8 Phase analysis

The phase diagrams of the samples demonstrate the amplitude and phase of each frequency component as shown in figure 7. From the figures below, it can be observed in case of robotic voice; the sine waves lost their features and appear in the form of sharp and straight lobes which is quite abnormal. However, in case of original voice, the sine waves contain amplitude variations and sine waves formed by varied frequency components. The sine waves so formed seem to contain maximum information. It supported the fact that data is lost when normal human voice is converted into any kind of filtered voice, specially a robotic voice.

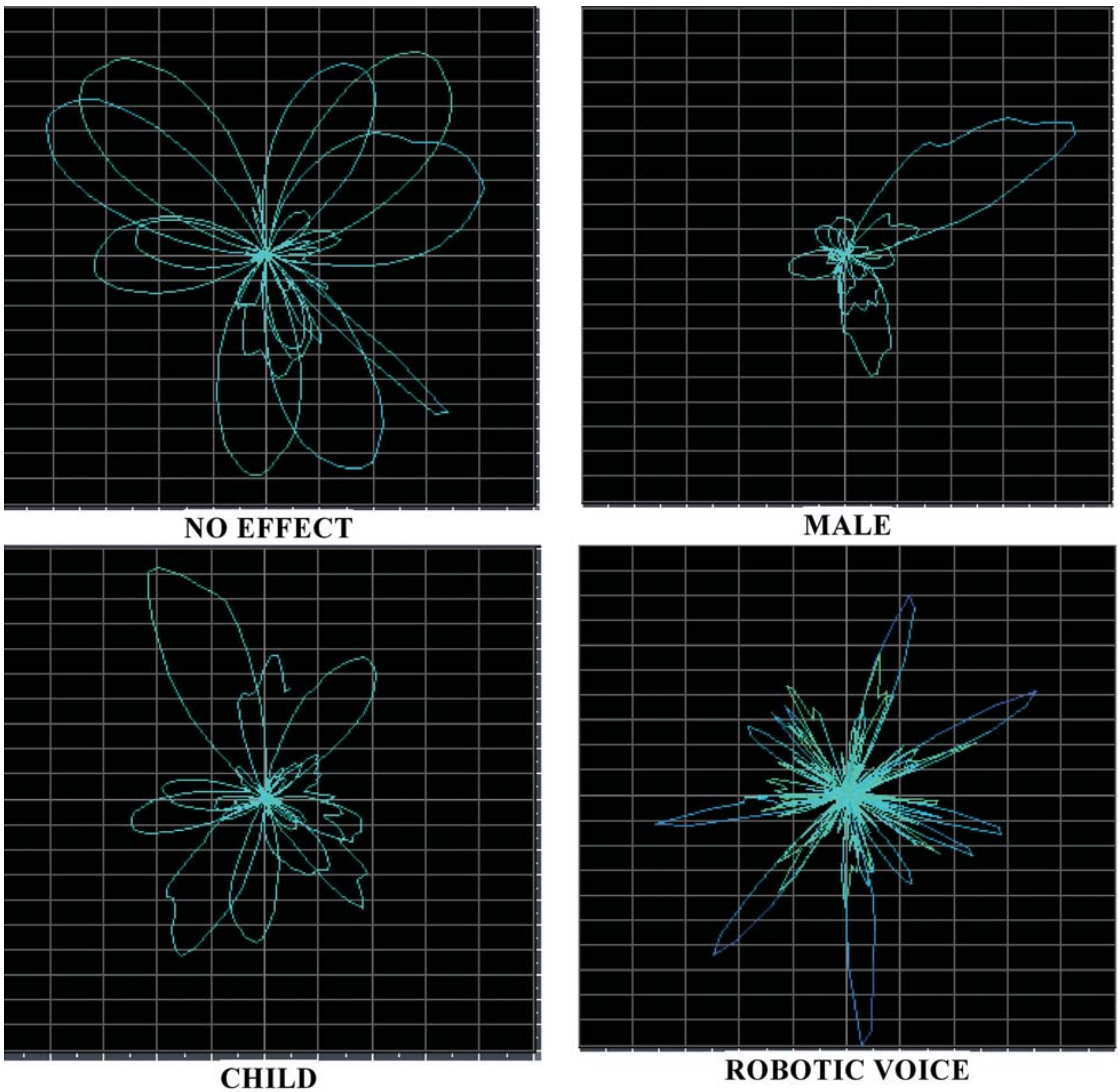


Fig. 7. Comparison based on Phase analysis.

3.9 Hex analysis

In case of hex analysis, both .mp3 and .wav samples were studied. It was observed that the conversion of the files from .mp3 format to .wav format lead to loss of information and hence, loss of hex data as seen in figure 8. However, the file header "riff" which is a file extension for .mp3 files was still present. It

Fig. 8. Comparison based on hex dump (.wav files).

can be vividly seen from the figures that maximum data was lost in case of the robotic filter and least amount of data was lost in case of the original sample. Some data was retained both in the male and child filtered voice. It clearly symbolized the loss of data from the audio signals when the voice was converted from original to robotic (filtered). However, it also proved that whenever a filter is applied on an original signal, be it the male voice filter or the infant voice filter, it reduces the amount of data contained in the signals by a significant and noticeable amount. Apart from this, the only observation which could be drawn from the hex data of the .mp3 files was the presence of the MP3 encoder "LAME".

3.10 Metadata analysis

No significant changes were found in the metadata properties of both .mp3 and .wav files.

4. CONCLUSION

To conclude, it can be vividly seen that all the aforementioned observations hold true as they can be easily seen in the respective figures. Hence, the results of this experiment were quite convincing. The changes were highly significant. Based on all these observations, a forensic examiner can easily differentiate between an original and a filtered / synthetic speech sample. This study can prove to be a boon to forensic scientists as it will provide a strong support to their findings and they will be able to defend themselves in the court of law. The future scope of this study includes the location of one or multiple common features in the original and the filtered voice which can relate them with each other; so that, in case a filtered voice recording arrives as an exhibit, the examiner can trace back the origin / speaker from the common characteristics and can easily correlate the original and filtered voice samples and prove them to belong to the one individual speaker / perpetrator in front of the jury.

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Noise mapping : A comprehensive analysis from India and around the world

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ABSTRACT

Environmental noise pollution has emerged as a critical issue in urban areas, posing significant risks to public health and well-being. Noise mapping has proven to be a vital tool in assessing, managing, and mitigating its impact by providing spatial representations of noise levels. This review paper presents a comprehensive analysis of noise mapping practices from both global and Indian perspectives. The study examines the methodologies, technologies, and policies, with a focus on participatory role and its influence in achievement of Sustainable Development Goals (SDGs). Globally, noise mapping has been successfully integrated into urban planning and public health frameworks, particularly in Europe and North America, where it informs noise action plans and regulatory measures. In India, multiple efforts have laid the foundation for systematic noise monitoring and mapping which are still in developing stage. However, challenges such as monitoring continues noise, data granularity, public awareness, and enforcement continue to hinder the effectiveness of noise control measures. This review highlights the need for a more cohesive approach to enhance noise mapping efforts in India. that leverages advancements in Geographic Information Systems (GIS), robust data collection, and public engagements.

1. INTRODUCTION

Noise, often defined as unwanted or harmful sound, is a significant environmental pollutant that can adversely affect human health and well-being, as well as wildlife. Noise pollution is a pervasive environmental issue with a significant impression on the quality of life, public health and environmental sustainability. Chronic subjection to lofty noise levels has been linked to various adverse health effects, including cardiovascular diseases, sleep disturbances, stress, and impaired cognitive function in children (Basner *et al.*, 2014). As urbanization and industrialization continue to accelerate, the need for effective noise management strategies becomes increasingly critical (Orikpete and Ewin, 2023). One of the most effective tools for understanding and mitigating noise pollution is noise mapping. Noise mapping is a crucial technique used to visualize and analyze the spatial distribution of noise levels within a specific area. The process of noise mapping typically includes several steps: data collection through sound level measurements, identification of noise sources, application of noise modelling techniques, and the creation of visual maps using GIS software. By collecting sound level data through various measurement methods and integrating this data into Geographic Information Systems (GIS), noise maps are created to identify areas with high noise pollution (Murphy *et al*, 2006). Noise mapping considers various noise indices, such as the equivalent day-evening-night level (L_{den}), continuous sound level (L_{eq}) and percentile noise levels (L_{10}, L_{50}, L_{90}) (González *et al.*, 2007), each of which provides specific insights into the intensity and variation of noise over time. The integration of these attributes allows for a comprehensive detailed spatial understanding of noise pollution, allowing for the identification of noise hotspots (Bilaşco *et al.*, 2017) and the assessment of noise exposure across different regions (Murphy & King, 2010). Various methodologies and software tools have emerged to upgrade the accuracy and reliability of noise maps. Comparative studies have shown that while different tools offer varying levels of precision, all contribute to a comprehensive understanding of environmental noise (Tinoco & Carvalho, 2020).

The attributes of noise mapping include temporal and spatial resolution, data sources, and the methodologies employed for noise level estimation. Temporal resolution refers to the frequency at which noise data is collected, which can range from real-time monitoring to periodic sampling over days, months, or years (Alam *et al.*, 2017). Spatial resolution, on the other hand, determines the granularity of the noise map, with higher resolution maps offering more detailed insights into noise distribution across smaller areas (Comesaña *et al.*, 2016). The selection of data sources, such as traffic flow, industrial activities, and natural soundscapes, also plays a pivotal role in ascertaining the accuracy and relevance of the noise map. The noise modelling plays a crucial role in the development of noise maps (Murphy and King, 2022). The primary function of modelling in noise mapping is to fill in gaps where direct measurements may not be feasible or practical, thereby creating a comprehensive and continuous representation of noise levels over a wide area. Multiple mathematical noise models and statistical noise models are constantly being developed for enhancement in noise prediction and estimation (Mann and Singh, 2022). This predictive capability allows for the assessment of future noise scenarios. The conventional way to develop holistic noise maps is achieved through numerical simulations for the estimation of urban acoustic sources' noise levels (Smiraglia *et al.*, 2016; Bozkurt and Demirkale, 2017). These maps are essential for urban planners, policymakers, and environmental agencies to design targeted noise mitigation strategies (Can *et al.*, 2008). In essence, noise mapping is a vital tool in combating noise pollution. By offering a clear and actionable depiction of noise data, it aids informed decision-making (Licitra and Memoli, 2008) and the execution of effective noise control measures, thereby fostering healthier and more sustainable living environments. The creation of a noise map necessitates the incorporation of data from an extensive array of noise sources, along with their associated parameters. These parameters include but are not limited to, road traffic flow, vehicle classification, urban morphology, meteorological conditions, and more. Concurrently, it is imperative to examine the acoustic propagation paths of these sources (Aumond *et al.*, 2018) in relation to various types of noise, as well as the attenuation of sound as it traverses through different geographic features and architectural structures (Bozkurt and Demirkale, 2017). This process significantly contributes to the slow update frequency of noise maps, as well as the elevated cost associated with their production. (Kephalopoulos *et al.*, 2014; Can *et al.*, 2018).

The present review highlights the Indian and International scenarios regarding noise mapping and its attributes, adopted methodology adopted for proper planning and management of noise control in urban scenarios.

2. NOISE MAPPING STRATEGY AND APPROACH

Noise mapping internationally is a critical tool for managing environmental noise, protecting public health, and guiding sustainable urban development. The consistent application of international standards ensures that noise mapping efforts are effective and comparable across different regions and countries. Mapping can be done specifically for individual sources of noise such as road traffic, railways, aircraft, industries, and so on, or in combination with multiple sources under acoustic environment analysis to assess the holistic noise environment. (Garg *et al.*, 2015). Noise maps provide a spatial representation of the acoustic condition that can be employed in the analysis and management process. The impact of noise can also be calculated in GIS (Geographical Information System) by integrating noise levels with the location of

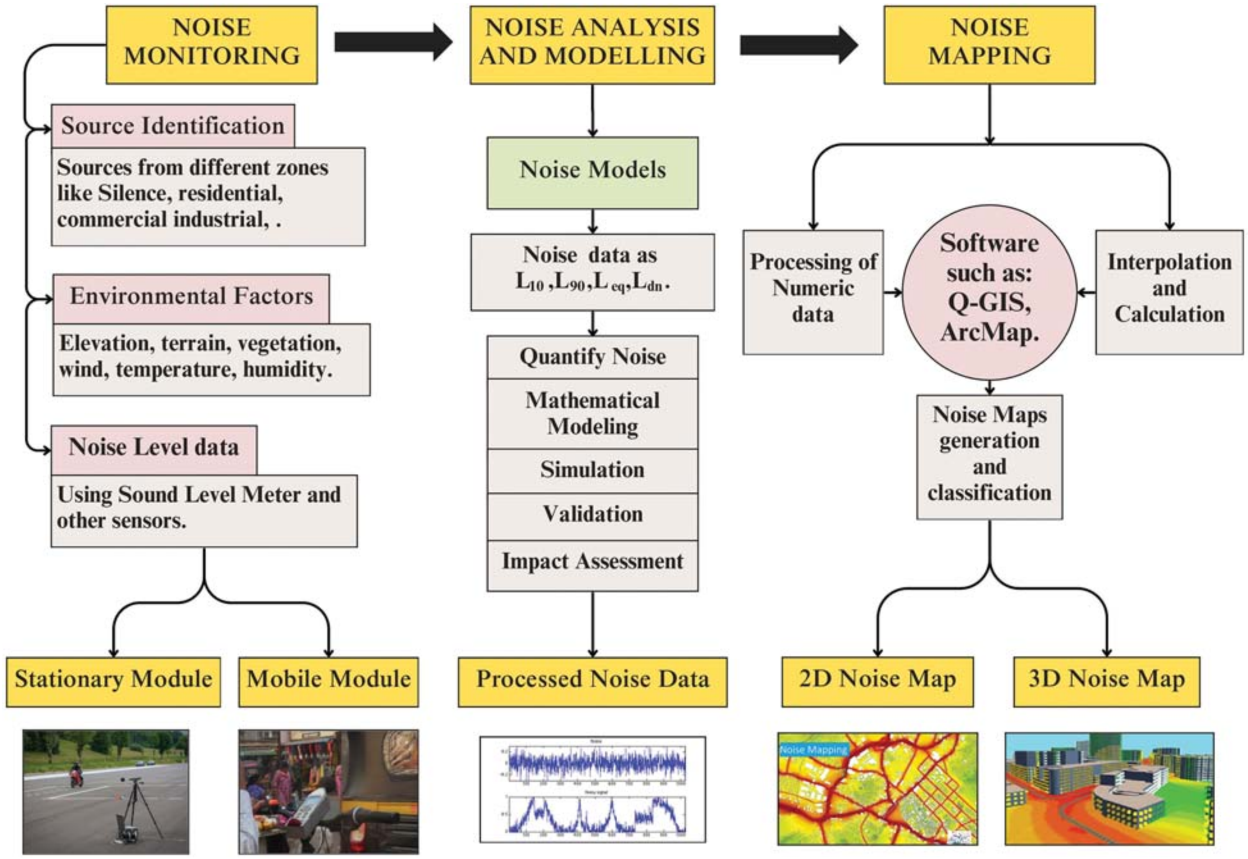

Fig. 1. Noise Mapping Approach.

persons living in the region and their sensitivity to noise (Karthik *et al.,* 2015; Cho *et al.,* 2007). Without rigorous noise mapping, the spatio-temporal distribution of noise fluctuations is difficult to assess and quantify. The right use of GIS in mapping noise effects allows for the optimization of the quality and efficiency of noise effect research [de Kluijver and Stote, 2003]. Since the implementation of the Environmental Noise Directive, many European countries have employed strategic noise maps to manage noise (Zhang *et al.,* 2023). The European Noise Directive (European Commission) mandates that every five years, for agglomerations with a population of 100,000 or more, Member States create noise maps and action plans for noise reduction to assess the noise exposure of the general public. Developed countries have completed noise mapping projects utilizing cutting-edge instruments and methodologies. The process of noise mapping generally involves data collection, and data analysis having multiple components which all adhere to the purpose of the noise mapping. The thorough process of the noise mapping and its different components are presented in Figure 1.

2.1 Noise Monitoring

Data collection is a critical phase in noise mapping, as it provides the foundational information needed to accurately assess noise levels and understand their distribution across a specific area. The process involves gathering data on noise levels, identifying noise sources, and accounting for environmental factors that influence noise propagation. The noise monitoring consists of multiple parameters that define the efficiency and precision of noise levels captured. The number of locations undertaken for the development of noise maps is one of the essential factors. The legal authorities all over the world have divided the areas into multiple zones which have their own characteristic and acoustic patterns and have assigned permissible noise limits accordingly. The noise monitoring network must be established such that each zone having a specific acoustic pattern is undertaken to generate noise mapping, ensuing holistic strategy and approach. Representative locations of monitoring must be such that it can cover the entire area being studied, including residential zones, commercial areas, traffic intersections, industrial sites, quiet zones etc. Secondly, the noise instruments being utilized for the noise monitoring must be calibrated and adhere to the IEC 61672 for a standardized approach. Multiple noise indices are available for a thorough representation of the acoustic environment of the area being monitored. The selection of a particular index or multiple indices depends on the objective of the noise mapping that is being carried out for a specific area. The monitoring period is also an essential parameter that has an influence on the decision-making regarding the adopted noise methodology. Since the acoustical pattern of a respective area generally differs in the daytime and night time hence the monitoring sessions depend heavily on the objective and purpose for which the noise mapping is being carried out. Nowadays, especially in urban areas, the noise patterns differ on working and non-working days (Dey *et al.*, 2021). Different seasons can also affect noise levels, particularly in areas with seasonal activities or changes in environmental conditions (Gaudon *et al.*, 2022). Hence considering the objectives of the noise mapping, the noise monitoring session can be undertaken. The last and major factors that influence the selection of a noise monitoring network are environmental factors and the topography of the area. The propagation of the noise differs based on the terrain features and the presence of vegetation. Trees and shrubs can act as natural noise barriers (Thakre *et al.*, 2024; Laxmi *et al.*, 2022), absorbing and scattering sound waves. The meteorological conditions like wind, temperature, humidity and precipitation also influence noise monitoring.

Various calibrated sensors can be used to measure the amount of noise pollution to obtain the temporal variation of the data. Stationary noise monitoring stations offer precise noise data with high temporal resolution, despite having limited spatial coverage because of their high construction and maintenance costs (Mioduszewski *et al.*, 2011; Zambon *et al.*, 2018; Monti *et al.*, 2020). In earlier investigations, Santini *et al.*, 2008 created a wireless sensor network to track noise pollution. But these days, a lot of sophisticated sensors have been created that are capable of collecting data very accurately (Mydlarz *et al.*, 2019). Saha et al., 2018 also designed a cloud-based sensor controlled by a Raspberry Pi to accomplish the same thing. Segura-Garcia *et al.*, 2017 is also employed as a stationary sensing technique to obtain environmental noise data. An advanced wireless sensor-based system is intended for the same purpose (Santini *et al.*, 2008). Other factors besides technological progress contribute to the unreliability of the sensors. Environmental risks like storms and rain can cause the sensors to malfunction or give false information.

Finally, mobile sampling is a method that has not received much attention. However, as mobile communication devices become more widely used, people can now measure noise levels with their own smartphones or even inexpensive hardware that has been specially made for the purpose (Kardous and Shaw, 2014). Realizing that ubiquitous technology can create a direct connection between people and data, the concept of participatory sensing was born. It uses everyday mobile devices, such as cell phones (Lokhande *et al.*, 2021), to create interactive sensor networks that let experts and laypeople gather, examine, and share local knowledge (Eric Paulos 2009). As a result, the big user base can create a dense mobile sensing network, which addresses the issues with the previous method's sparse nodes and high cost. It is now the direction that noise mapping techniques will take in the future. Participatory sensing is a sampling scheme that has garnered attention recently as well. It allows anyone to take measurements with specific measurement equipment with an accuracy comparable to standard noise maps (Kardous *et al.*, 2014; D'Hondt *et al.*, 2009).

In addition, installing a noise sensor on a bicycle demonstrated better results when applied to heavily travelled roads. Mobile systems for continuous monitoring could react much more quickly and reliably to any change in the surrounding conditions that affect noise (Ruiz-Padillo *et al.*, 2016). On the other hand, researchers using professional sensors or smartphones (Can *et al.*, 2014) or while riding bicycles (Quintero *et al.*, 2021; Quintero *et al.*, 2019) or walking (Guillaume et al., 2019) conduct mobile monitoring. Because of their brief stays while moving constantly, (Leao *et al.*, 2014; Zappatore *et al.*, 2016) provide a reduced temporal resolution paired with increased spatial resolution. However, it is challenging to avoid the issue of data sparseness when collecting data using wireless sensors or mobile devices. Sparse learning has been used in data recovery research recently by numerous studies. (Rani *et al.*, 2018). While fixed sensor-based devices are used for temporal data collection, smartphones are primarily used for spatial data collection. The sensitivity problem with smartphones and the absence of suitable techniques for calibration make infrastructure-based sensing appear more feasible. Noteworthy studies have proposed using wireless sensing for data collection to overcome the drawbacks of the previously mentioned techniques. (Marouf *et al.*, 2018).

2.2 Noise Analysis

Data analysis in noise mapping is a multi-step process that transforms raw noise data into meaningful insights about the noise environment. It involves statistical analysis, spatial and temporal modelling, source apportionment, and compliance checks, all of which contribute to creating accurate noise maps and informing noise management decisions. Proper data analysis helps identify noise hotspots, assess the impact on public health and the environment, and guide effective noise mitigation strategies. Noise indices like Equivalent noise level (L_{eq}), Maximum noise level (L_{max}), Minimum noise level (L_{min}), Statistical noise levels (L_{50}, L_{90}, L_{10}), Day Evening Night Sound Level (L_{den}) etc. are used for sound level data analysis. Additionally, Noise Pollution Level (LNP), Traffic Noise Index (TNI), and Noise Exceedance Factor (NEF) (Kalawapudi *et al.*, 2020) are also used to evaluate the annoyance levels, particularly attributed to traffic noise detection and mapping. Social media networks and computer technology advancements are a new source of developing data sources and research tools for scientific research. Recently, data from social media platforms being retrieved regarding noise pollution (Aiello *et al.*, 2016) such as Flickr (Gasco *et al.* 2019) and Twitter (Meddeb *et al.* 2020) for data analysis.

2.3 Noise Modelling

In recent years, many scientific models have been developed with this aspect in mind, introducing empirical formulations that are limited to source emission and sound propagation. In addition to the source characterization, the sound propagation effects are solved using sophisticated numerical techniques like the wave equation and continuity equation. To forecast sound pressure levels that are set by government authorities and described in terms of L_{eq}, L_{10}, etc., noise prediction models are frequently required (Golmohammadi *et al.*, 2009). Thus, to accomplish the final goals, these models make use of highly efficient computers and knowledgeable operators. Numerous nations have created their own approved noise prediction models (Garg 2014). The user may choose any noise model for noise predictions and map generation in several widely used modelling packages, including CadnaA, Sound PLAN, and Predictor-LIMA. The main concerns for accurate forecasting and predictions are the noise modelling software, input data accuracy, validation and usability, and noise map calibration. In recent years, many countries have adopted noise models that have been developed for various sources of transportation-related noise. information on every road traffic noise model, including the US Federal Highway Administration (FHWA) model, the UK's CoRTN (Calculation of Road Traffic Noise) model, Germany's RLS90 model, Japan's ASJ RTN 2008 model, and Europe's HARMONOISE model (de Lisle 2016; Khayami *et al.*, 2019). The main advantage of using this kind of software is the simulative platform, which can be useful in creating plans for noise control actions aimed at regulating the ambient noise levels of a specific area or site. It should be mentioned that before being used, each of these models was approved by the relevant nation. These models may be effectively used to predict sound levels in the short term, but for long-term day-and-night equivalent level predictions, the model's accuracy and the input data-such as traffic flow and vehicle speed-are critical to producing predictions that are dependable and have few errors.

2.4 Noise Mapping

It is difficult to create a noise map where noise monitoring is not carried out so that the software or noise prediction model can fill the void. Therefore, scientific analysis and comparison of these models are necessary to determine their general suitability as well as the optimal strategy for noise mapping. The noise models are integrated with a GIS interface to produce noise maps. When GIS and noise models are integrated, noise maps can be generated from supporting digital geographic data. The noise data is gathered, stored, managed, and governed with the help of the GIS database management system. Based on a variety of GIS-compatible interpolation methods, noise contours can be generated. GIS platform can build noise maps using interpolation methods such as inverse distance weight (IDW), Kriging, and radial basis interpolation methods (Aumond *et al.*, 2018). The integration of noise levels with GIS will help in the preparation of noise maps.

3. NOISE MAPPING AND SUSTAINABLE DEVELOPMENT GOALS

Noise mapping plays a crucial role in identifying noise pollution hotspots, guiding informed decision-making, and facilitating targeted mitigation efforts. By providing a detailed visual overview of noise levels, authorities can focus resources on critical areas, such as neighbourhoods near highways or industrial zones. This data-driven approach enhances urban planning by ensuring residential developments are situated away from high-noise zones and supports the creation of effective noise regulations. Noise maps also allow for the evaluation of mitigation strategies, such as noise barriers, by comparing pre-and post-intervention data. Public awareness is increased through accessible noise maps, fostering community engagement and support for noise reduction initiatives. Additionally, noise mapping ensures regulatory compliance, aids in strategic planning by forecasting future noise levels, and informs health impact assessments by linking noise exposure to health issues. Ultimately, reducing noise pollution through informed strategies offers significant economic benefits, including higher property values and improved productivity in quieter areas. The benefits of noise mapping are displayed in Figure 2.

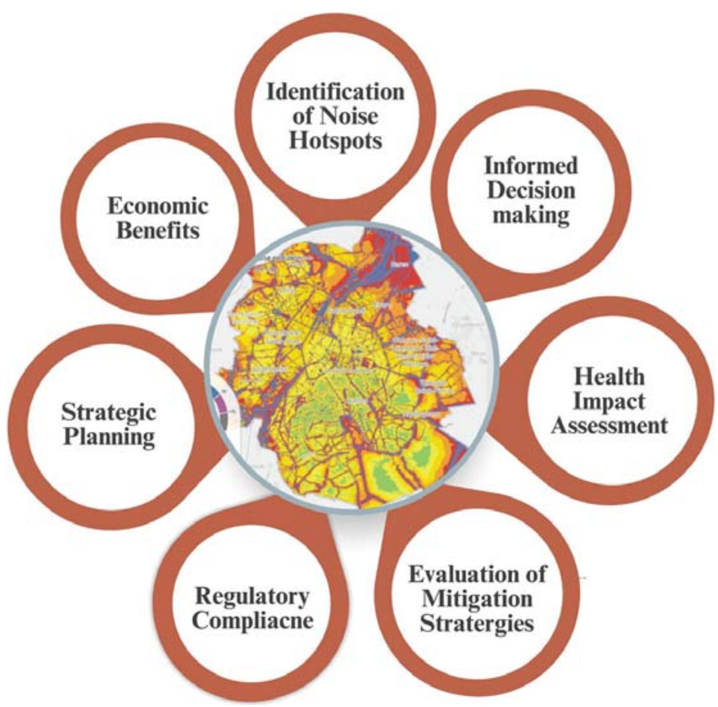

Fig. 2. The application horizon of noise mapping.

Noise mapping is instrumental in advancing Sustainable Development Goals (SDGs) by offering crucial insights into noise pollution and its effects. Noise pollution is intrinsically linked to achieving several Sustainable Development Goals (SDGs) (King, 2022), as managing noise can significantly enhance health, urban sustainability, biodiversity, and industrial innovation. The major influence of noise pollution on the

Fig. 3. Noise mapping and its role in sustainable development goal.

SDG goals is presented in Figure 3. For SDG 3 (Good Health and Well-Being), noise maps identify high-exposure areas, enabling targeted interventions to mitigate health risks associated with noise, such as cardiovascular problems and sleep disturbances (King 2021). In alignment with SDG 11 (Sustainable Cities and Communities), these maps inform urban planning, helping to design quieter, more livable cities by optimizing traffic flow and integrating green spaces (Asiamah and Sadegah, 2022).

For SDG 15 (Life on Land), noise mapping assists in protecting wildlife by pinpointing areas where noise disrupts natural habitats and animal behaviour. Under SDG 9 (Industry, Innovation, and Infrastructure), noise maps guide the development of quieter industrial practices and infrastructure. Lastly, SDG 17 (Partnerships for the Goals) benefits from noise mapping by fostering collaboration among governments, businesses, and communities to address noise pollution collectively. Overall, noise mapping supports data-driven decision-making, effective policy development, and community engagement, contributing to a healthier and more sustainable environment. By integrating policy, technology, and community engagement, noise pollution can be effectively managed, contributing to the broader achievement of the SDGs.

4. GLOBAL AND INDIAN PERSPECTIVE ON NOISE MAPPING

4.1 International Scenario

Europe has been a forerunner in recognizing the risks associated with noise pollution and enacting laws to mitigate them because of its advanced technology. The European region was among the earliest to recognize the health and environmental repercussions linked with uncontrolled noise exposure. Considering this European Union directed states to develop strategic noise maps for different sources viz. railway, road, industrial sites and airports. These maps were supposed to give insights into an overall scenario of noise levels and their influence across various regions. Based on the insights received from the noise maps, member states were called to prepare and execute action plans to reduce noise pollution, ensuring effective methods to protect public health and raise the quality of life for European residents. This active approach has made Europe a pioneer in noise pollution management and has set an example for others to follow (Directive 2002/49/EC).

3D noise mapping was attempted in the Netherlands (Stoter *et al.*, 2008), using the triangulated irregular network (TIN), inverse distance weighted (IDW), and Kriging methods with the help of GIS. In 2003 (Manvell 2004), the Municipality of Madrid started an automated noise mapping procedure to create a dynamic noise map system called SADMAM (Sistema Actualización Dinámica Mapa Acústico Madrid), which would be used for data post-processing. To measure the sound pressure levels at key places, mobile monitoring equipment outfitted with GIS systems was utilized. A participatory sensing framework named NoiseTube was proposed by D'Hondta and Stevens, 2011 regarding ambient noise monitoring and mapping for the city of Antwerp, Belgium. It was concluded that participatory sensing allows for person-centered collection of environmental measurement data, offering, in principle, high spatial and temporal granularity. In accordance with the European Directive 2002/49, noise maps were developed for shaping land use policies and designing acoustic mitigation plans in several Portuguese cities (Coelho and Alarcao, 2015). The study by Aletta and Kang, 2015 uses CadnaA for noise mapping in Brighton, UK. The study integrated approach towards mapping involved combination of three perspectives i.e. noise, sounds and perception making the methodology effective for the derivation of the design's relevant information. Deng *et al.* 2016 attempted 3D noise mapping dedicated towards traffic noise with the help of GIS and building information modelling (BIM) integration. For noise calculation the noise model Italian Consiglio Nazionale delle Ricerche (C.N.R.) model (Cannelli *et al.*, 1983) is used for prediction of traffic noise. Using the dynamic noise maps, people can realize the noise distribution in the urban areas and conduct some proper measures on noise control easily. Quintero *et al.* (2019) created a modelling framework to evaluate the statistical needs for creating noise maps in Lyon, France's northeast region based on mobile observations. 95% of the mobile samples, according to their framework, fell between [-3.0, 2.2] dBA in terms of estimation error. Benocci *et al.* (2019), displayed the application of DYNAMAP system in the city of Rome by developing a real time dynamic mapping system with the use of monitoring data and static noise maps. Benocci *et al.* (2021) focused on the "real-time" acoustic maps in a district of Milan under project DYNAMAP which has a network of permanently installed noise monitoring stations. customized low-cost sensors with tools that integrate into the GIS platform. Multiple road segments having same traffic noise characteristics are clubbed together to develop a dynamic noise map. Baclet *et al.* (2023) propose a strategy for a near-real-time dynamic noise mapping that enables the generation of dynamic noise maps with the calculations of advanced noise exposure indicators for Tartu, Estonia. The approach incorporates the real-time traffic quantification through a limited network of integrated sensors and employs two software packages: Noimse Modelling and SUMO.

Wei *et al.* (2016) proposed a model for a dynamic noise map with the noise indices L_{eq}, L_{10} and L_{90}; updating every 15 minutes using a limited number of noise monitoring devices. The study concludes 75% closer predictions for L_{eq}, 55% and 90% for the L_{10} and L_{90} respectively. For spatiotemporal noise mapping dedicated to road traffic noise, Lan *et al.* 2020 proposed distribution relies on two variables namely traffic density and speed and multisource data is used to analyse the spatiotemporal characteristics for the region of Chancheng, Guangdong Province southern China. Gathering high-precision noise data with excellent spatial and temporal resolution. The Latent Factor Model (LFM) was developed based on crowd-sensing technology for reducing the data sparseness in the noise map called Spatial-Temporally Related LFM (STR-LFM) in the Guangzhou, South China. Spatiotemporal correlation offered greater stability when dealing with data sparsity across various levels (Huang *et al.* 2021). Utilizing the multisource data 2D and 3D dynamic noise maps are developed for Taipei City, Taiwan, with a limited number of sensors. The 2D noise model showed a deviation ranging from -6.25 dBA to -4.46 dBA and 3D noise model displayed a prediction error ranging from 0.02 dBA to 1.93 dBA (Tang *et al.*, 2022). Wang *et al.* (2022) adopted a cutting-edge approach by leveraging web crawler technology and text mining to map and analyse noise pollution across China using data from social media platforms. Zhang *et al.* (2023) introduced a novel noise monitoring approach merging the benefits of both stationary and mobile monitoring techniques called the Rotating Mobile Monitoring method (RMM) in Haidian, Beijing. Masum *et al.* (2021) analysed the spatiotemporal variability using ArcGIS's inverse distance weighting (IDW) technique for noise descriptors and pollution indices within Chattogram City Corporation (CCC) in Bangladesh. Land use regression (LUR) model using geospatial analysis was used for the determination of spatial variability in Shiraz, Iran by Gharehchahi *et al.* (2024). Lden and Lnight were used for the development of LUR model which is claimed to capture the variability in the noise level while rendering a noise map of high resolution.

Using limited information and modelling by CadnaA software, noise maps were developed for the city of Santiago de Chile by Suarez and Barros, 2014. Traffic noise mapping for small cities was proposed by Bastián-Monarca *et al.*, 2016. The study was carried out in Valdivia, Chile in which clustering of building blocks and classification of vehicular volume with the help of noise modelling using RLS-90 rendered low-cost and efficient noise maps developed with CadnaA software. During COVID-19, noise mapping for Rio de Janeiro, Brazil was performed by Gevu *et al.*, 2021 using Predictor software for noise simulation. The study mapped the difference between before and during the COVID-19 pandemic scenario using noise maps. For noise mapping of the hospital region in the city of Sorocaba, Brazil, iNoise software (DGMR Software, Netherlands) was used for the development of noise maps by Andrade *et al.*, 2024. For noise mapping in the city of New York, complaint data, social media, road networks and Point of Interests (POIs) as data sources were used by Wang *et al.*, 2014. Fiedler et al. (2015) employed Predictor software to conduct noise mapping calculations at major traffic hubs in a Latin American metropolis. The grid size was set at 10x10 meters, with a finer resolution of 2x2 meters applied to sensitive areas. Baffoe *et al.* (2022) applied overlay techniques in the ArcGIS environment to assess noise pollution in the Tarkwa Mining Community of Ghana. The study involved overlaying maps of various diseases, including sleep disturbance, hypertension, cardiovascular issues, and ear problems, onto noise maps within GIS to analyze the correlation between noise pollution and these health conditions.

4.2 Indian Scenario

The Central Pollution Control Board (CPCB) has undertaken several initiatives and conducted extensive studies to monitor ambient sound levels at noise hotspots in metropolitan areas, to implement effective noise mitigation measures. In the continuation of the efforts, CPCB, India launched the National Ambient Noise Monitoring Network (NANMN) as outlined in Section IV of the National Environmental Policy (NEP)-2006, which called for the inclusion of ambient noise as a standard monitoring parameter in designated urban areas. The NANMN project, established in 2011, aims to collect real-time continuous noise monitoring data. Currently, NANMN operates across seven major cities-Mumbai, Delhi, Kolkata, Bangalore, Chennai, Lucknow, and Hyderabad-with 70 continuous monitoring stations, ten in each of these cities, ensuring year-round noise monitoring (Garg *et al.*, 2016).

In 2009, using GIS, monitoring and mapping of noise levels due to traffic was conducted in Asansol, West Bengal (Banerjee *et al.*, 2008). Noise mapping of the environment with varied settings was carried out in the city of Chennai by Kalaiselvi and Ramachandraiah (2010). Alam. W., 2011 performed noise mapping using the kriging interpolation technique using ArcGIS for the city of Guwahati, Assam. In the city of Mumbai, which is known for its heavy road traffic congestion, a noise mapping study was carried out (Joshi *et al.*, 2015). Their research demonstrates a range of GIS methods used for making noise maps.

A study related to the same objective was conducted in Chennai City, where noise maps were prepared for various locations (Akiladevi *et al.*, 2015). To study the propagation of noise levels in nearby areas due to mining, noise mapping using Predictor LimA software with a grid size 10m x 10m was carried out by Manwar *et al.* 2016. Traffic noise monitoring was carried out by Kumar *et al.,* 2017 with the help of community participation through smartphones forming a smartphone-based community sensor network. With the fuzzy inference system built into the server, the classification of the records in the different levels of impact of noise pollution was presented. Dhawale *et al.* 2017 explored the spatial distribution of noise levels with adequate visualisation due to industrial and mining areas of Keonjhar, Odisha with the help of noise mapping developed with the help of Predictor LimA software. An innovative approach was adopted by Laxmi *et al.*, 2019 for noise monitoring over 700 locations through bicycles in the city of Nagpur, Maharashtra. The SLM was mounted on the bicycles with uniquely designed arrangements that rendered efficient monitoring in complex and stringent areas. The equivalent noise levels were integrated into a Geographic Information System (GIS), to generate spatial and strategic noise maps of the city. Using CoRTN model prediction for L_{10} values, noise maps were developed using ARC GIS software for the city of Vellore, Tamil Nadu by Manojkumar *et al.*, 2019. 2D noise maps using SoundPLAN for the city of Surat, Gujrat was attempted by Sonaviya and Tandel, 2019 with the help of noise data (L_{eq}, L_{10}, L_{90}, L_{den}, L_{max}, L_{min}), and other meteorological parameters. Some areas in Malad underwent spatial noise mapping and an exploration of the main sources of noise by Das *et al.,* 2019. Noise mapping using collaborative crowdsourcing using a smartphone application named NOISECAPTURE and plotting the analysed noise level in the ArcGIS platform was attempted for the city of Lucknow by Dubey *et al.*, 2020. Noise mapping was conducted in different locations of Guwahati and Delhi city, in which 3D noise maps were produced using GIS and Predictor LimA software (Alam *et al.*, 2020). For road traffic noise mapping, Sonaviya and Tandel, 2020 introduced a new honking correction factor integrated into RLS-90 noise model and developed noise maps using SoundPLAN software in the city of Gujrat. Mishra *et al.* 2021 assessed the traffic noise level in Delhi city at 10 locations through spatial distribution represented in the noise map created with the help of GIS with a minimum deviation of 4-7% between the measured noise level and predicted noise level. A thematic database was generated for the selection of representative noise locations such that all zones of selective areas are undertaking for holistic assessment of noise pollution by Dey *et al.*, 2021. Strategic and spatial noise maps are generated in the study using TIN model with the help of ArcMAP for the Mumbai city. In the same context, another crowd-sourcing approach was adopted by Lokhande *et al.* 2021 using android based application named "Noise Tracker" developed by the National Environmental Engineering Research Institute (CSIR-NEERI) and noise maps were developed with the help of Predictor LimA software. Using Inverse Distance weighted (IDW) interpolation and geostatistical analysis, noise maps were developed for Puducherry with a grid size of 500m x 500m by Devasia *et al.* 2022. Dubey *et al.* 2022 performed GIS mapping of short-span Noise Sensitive Events (SNSE) in Lucknow city on Diwali night with the help of crowd-sourced technique using a smartphone-based noise capturing application. To study the impact of traffic volume on noise level, noise maps using the IDW technique in ArcGIS software for a major road in the city of Hyderabad were developed by Balaji *et al.* 2022. With the help of MATLAB-based in-house noise model and artificial neuron network (ANN), noise maps were developed using GIS for the city of Raebareli by Zafar *et al.*, 2023. Mapping of traffic noise was attempted in Dhanbad city for visualization of noise levels and acoustic contour maps were developed in ArcGIS using the IDW technique by Patel *et al.,* 2024.

4.3 Future research and development

Multiple frameworks and methodologies have been adopted for noise mapping in the Indian scenario. Many statistical models have been developed in the country dedicated towards traffic noise, and industrial noise but still lack a defined traffic noise model like FHWA, CoRTN, RLS-90, CNOSSOS-EU etc. There isn't currently a validated noise model in Indian perspectives. Investigating the applicability of the various noise models for the Indian context is therefore crucial. Therefore, before using noise mapping software or tools in India for noise mapping studies, its validity and usability, which includes having algorithms for all of the major traffic noise models should be established. Examples of such software include CadnaA, Sound PLAN (Puckeridge *et al.*, 2019), Predictor-LIMA (El-Bardisy *et al.*, 2023), and others (Karantonis *et al.*, 2010). When distinct software packages are used with identical input data, notable variations may occur. Researchers have adopted these models and upgraded them for simulation in various scenarios. But India presents a very diverse traffic and noise environment, hence for precise noise modelling and mapping, accounting for various acoustical and non-acoustical parameters is still unexplored in the country. Like honking phenomena for Indian conditions differs from the world scenario, and it is one of the major contributors towards the overall urban noise environment in India. Researchers have considered honking as a parameter in noise traffic noise prediction model (Vijay *et al.*, 2015, Vijay *et al.*, 2018, Singh *et al.*, 2021, Aditya *et al.* 2020, Kalaiselvi and Ramachandraiah, 2016) and also characterized the honking noise based on different categories of vehicle (Thakre *et al.* 2020, Thakre *et al.*, 2018). Hence, honking is required to be undertaken as an essential parameter in the traffic noise model for enhancement in noise prediction and proper noise mapping. Multiple headers are presented in Figure 4 that can be guiding vane for the enhancement in the noise mapping scenario for India. Enhancing noise mapping in India requires expanding data collection networks with more monitoring stations and real-time sensors, leveraging mobile technology for crowd-sourced data, and integrating advanced GIS and modelling techniques. Tailoring noise models to local environmental factors, such as climatic conditions and diverse noise sources, is crucial. Public awareness and participation should be encouraged, alongside strengthening noise regulations and integrating noise mapping into urban planning. Integrating noise mapping with smart city initiatives can optimize traffic flow and reduce noise pollution. Advanced data analytics and AI should be used to enhance the accuracy of noise maps, while public awareness can be increased through user-friendly platforms providing real-time noise data. Detailed noise maps should inform policy development, enforcement, and health impact studies. Additionally, noise mapping should be mandatory in Environmental Impact Assessments (EIAs) for new projects, and cross-sector collaboration should be promoted to advance noise reduction strategies. Investing in research and utilizing machine learning and big data analytics can further refine noise predictions and management, leading to more effective noise control and improved urban living conditions.

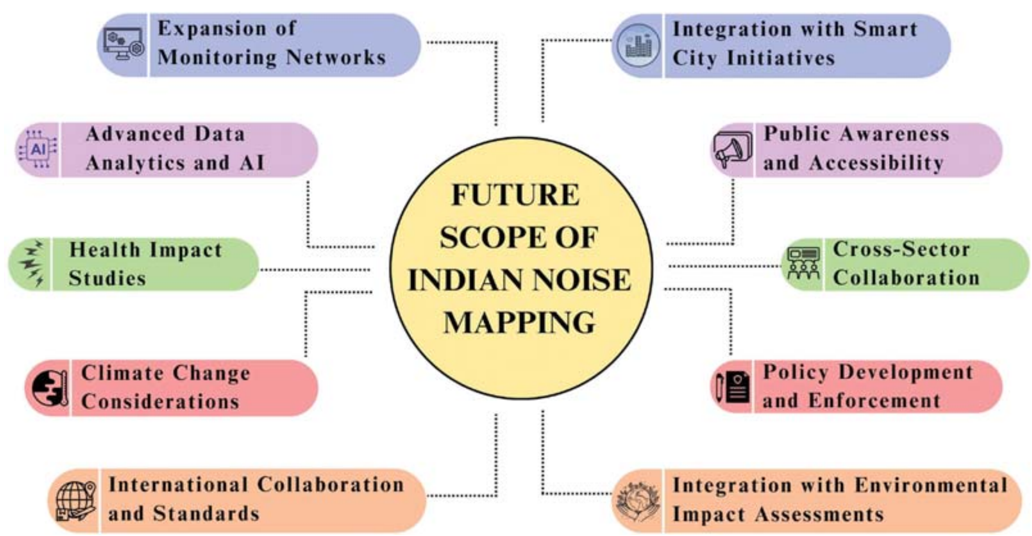

Fig. 4. Future scope of Indian noise mapping.

5. CONCLUSION

A comprehensive analysis of noise mapping, both internationally and within the Indian scenario, shows notable progress in the techniques and instruments applied for monitoring, modelling and mitigation of noise pollution. Strategies from across the globe, especially in Europe and North America, have established a benchmark in linking noise mapping with city planning and health policies, making a meaningful contribution to Sustainable Development Goals (SDGs). The adoption of detailed noise maps and plans in these areas has resulted in significant reductions in noise levels, improving urban living conditions. In India, various authorities have made significant strides in tackling noise pollution through organized monitoring and mapping efforts. Still, a noise mapping protocol and framework had to be delineated and developed considering heterogeneous traffic, prevalent honking, various noise sources and appropriate noise prediction models for Indian cities. The integration of Geographic Information Systems (GIS) with noise mapping framework further enhances the visualization of noise pollution and guides sustainable urban development and policy choices though its full potential is not yet being tapped in many Indian cities. Noise mapping highlights the necessity for a more comprehensive strategy that merges technological progress, data monitoring, analysis and active community involvement to tackle the alarming issue of noise pollution in Indian cities.

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Innovative sensor systems for health care Indian and Global perspectives

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ABSTRACT

Sensor systems are used in science and technology for various measurements in different disciplines. There are nano-systems and smart measurement systems available in industry and hospitals. However, newer and newer developments are coming up, day by day, in the field and hence, critical studies are required to be made, for better and precise measurements. In the present work, an overall description is given on innovative sensor systems for health care applications. Technological advances and innovations are given. Comparative analysis of the developments in the field are given. Case studies and practical applications are highlighted. Future of the sensor technology with possible new applications is discussed.

1. INTRODUCTION

The sensor systems are well available for the measurements in science, engineering, health care etc. Different types of sensor systems depend on the working principles like piezo-resistive type, piezoelectric type and bio-composite type[1-25]. According to the working principle, different types of sensors are of electrical/electronic type, electro-mechanical type, acoustic/ultrasonic type, optical type, chemical type, etc. Main innovate sensors are micro and nano type and smart in natute. Nano-semsors are useful in health care applications for precision measurements at quick and reliable manner. The data can be telemetered by using telemetry system, for getting information from remote and far off places. This is useful in case of old age patients.

- With the advancement of science, newer and newer sensors and devices are being developed for different types of scientific, engineering and medical applications.
- However, more research is required to be pursued for better devices, particularly for better health care of say old age patients, living in isolated areas.
- Thus, in the present research, advanced nano-ultrasonic -sensors and IOT basrd systems are presented, Main emphasis is placed on the design and development aspects of macro- to nano-ultrasonic sensors and IOT ststems for better healthcare and industrial control applications.
- Different types of nano-sensors, viz., piezo-resistive and piezo-electric types and biochip-based sensors are discussed for novel diagnostic and therapeutic applications.

- Development of IOT and cloud-based biomedical sensor systems is given for new clinical measurements in ubiquitous manner, with WSN (Wireless Sensor Networking)
- Cancer nanotechnology and therapeutic treatment of deep seated brain tumours, with intense focussed ultrasound are given, as case studies here.

2. BASIC SYSTEMS

Health care in hospital environments is required for the comfort of the patients, staff and others working in the hospital. Appropriate sensors, devices, systems and hardware are used. Appropriate acoustic requirements of the environment are used[5-25].

- As is aware, with the advancement of science, newer and newer sensors and devices are being developed for different types of scientific, engineering and medical applications.
- However, more research is required to be pursued for better devices, particularly for better health care of say old age patients, living in isolated areas.
- Thus, in the present research, advanced nano-ultrasonic -sensors and IOT basrd systems are presented, Main emphasis is placed on the design and development aspects of macro- to nano-ultrasonic sensors and IOT ststems for better healthcare and industrial control applications.
- Different types of nano-sensors, viz., piezo-resistive and piezo-electric types and biochip-based sensors are discussed for novel diagnostic and therapeutic applications.
- Development of IOT and cloud-based biomedical sensor systems is given for new clinical measurements in ubiquitous manner, with WSN (Wireless Sensor Networking)
- Cancer nanotechnology and therapeutic treatment of deep seated brain tumours, with intense focussed ultrasound are given, as case studies here.

3. INNOVATIVE TECHNOLOGIES

3.1 General

As usual, day by day, new acoustic and physical innovative technologies are being developed and hence novel scientific measurements are possible for good results and for new avenues in the environment. Health care technology is very important for better health care. Ubiquitous technology is possible to be used for any measurement, anywhere, anytime[3-8].

3.2 Acoustop-fluidic Point-of-Care As Diagnostics

The contactless, biocompatible nature of acoustic waves, along with its versatility, excellent spatiotemporal resolution, and a high potential for customization (i.e., many acoustic parameters that can be tuned over a wide working region-operating frequencies from the kHz to GHz range), enable them to become a powerful platform for point-of-care diagnosis[15,16]. As an example, multiple "acoustic tweezers" technologies have been developed to separate bioparticles based on minute differences in their physical

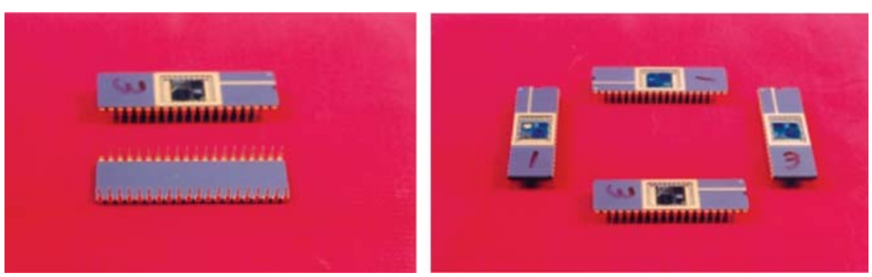

Fig. 1. Piezo-resistor BP bridge.

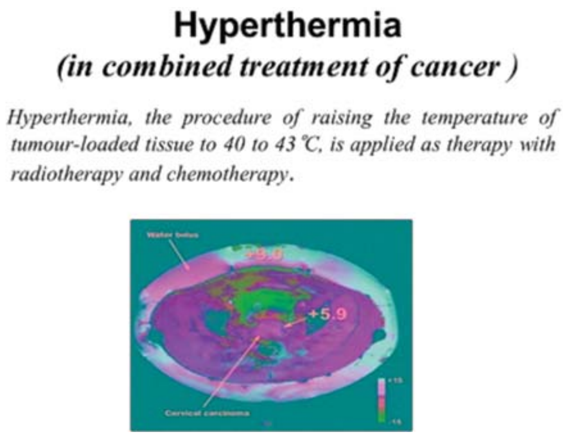

Fig. 2. Is the photograph of cancer detection with ultrasound.

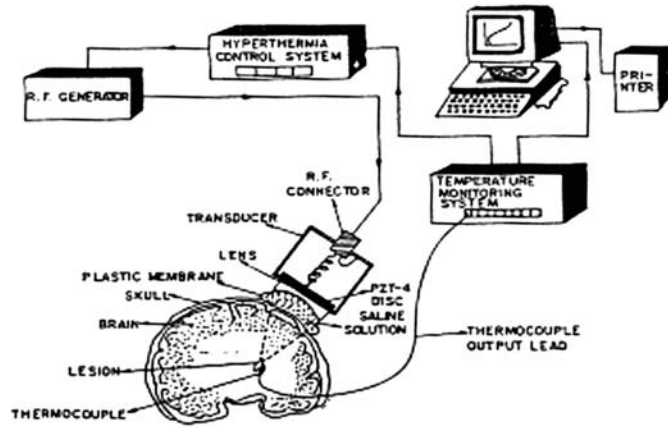

Fig. 3. Is the ultrasonic hyperthermia.

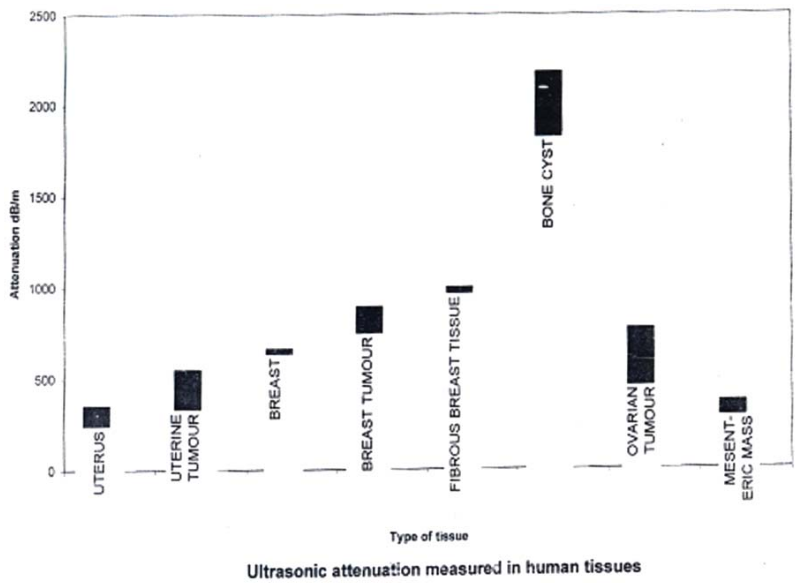

Fig. 4. Acoustic tissue data.

properties[17-23]. Isolation of biomarkers for circulating tumor cells from white blood cells[20] and peripheral blood samples[23], to show potential in early cancer detection and diagnostics. Recent studies show , the spatial resolution of acoustic tweezers technology tp be used in focused on using acoustic tweezers to isolate nanometer-sized extracellular vesicles called small extracellular vesicles (sEVs) from various biofluids[18,24].

4. SCIENTIFIC MEASUREMENTS

Novel scientific measurements are now made for quick and reliable results. Health care systems are better these days for monitoring day to day health. Kirti Gandhi Bhatia, Sanjiv Bhatia and V.R. Singh have studied acoustic parameters of cancerous tissues in the Laboratory.

Acoustic parameters like ultrasonic velocity and attenuation have been measured in mesenteric lymphoma *in-vitro*. Ultrasonic velocity in these samples has been found to be in the range of 1669 ms^{-1} to

1697 ms^{-1} with mean value of 1681 ms^{-1} while attenuation ranging from 286 dBm^{-1} to 369 dBm^{-1} with mean value of 329 dBm^{-1}. The present study would assist in proper ultrasonic therapy planning for solid tumours and also differentiating these from mesenteric masses like inflammatory, benign, neo plastic and others in pre therapy planning.

Five samples of lymphoid tissues of mesenteric mass were collected from department of pathology, King George Medical University, Lucknow, India of patients of age 35 to 45 years. All samples were preserved in 10% formalin solution. Their parallel sections were made with scalpel. They all were hard and firm masses, cut with gritty sensation Fig. 5.

Fig. 5. A Double-Probe through transmission technique for measurement of acoustic parameters.

Sample was kept between two matched ultrasonic transducers as transmitter and receiver of same frequency (3.5 MHz) made at NPL, New Delhi, India by using discs (10 mm in diameter of PZT-5 (lead zirconium titanate) material[4]. An ultrasonic pulser-receiver (Panametrics model 5052 PR) was used to excite the transmitting transducer. The pulses after passing through sample were received by another matched transducer then displayed on cathode ray oscilloscope (OS 300C-20 MHz, L&T Gould make). Pulse transit time for known propagation distance was measured from the calibrated cathode ray oscilloscope screen that gave velocity. Attenuation was calculated using formula $\alpha = \{20\log(e_1/e_2)\}/d$, where e_1 and e_2 are the amplitudes in terms of voltage signals of the transmitted and received pulses, respectively and d the distance traveled by the pulse or thickness of sample. Densities (ρ) of samples were also measured by Archimedes's principle[8-28].

Ultrasonic velocity in these samples have been found to vary from 1669 ms^{-1} to 1697 ms^{-1} with mean value 1681 ms^{-1} and attenuation from 286 dBm^{-1} to 369 dBm^{-1} with mean value 329 dBm^{-1}. Soft tissue sarcomas and primary gastrointestinal malignancies as given in different references[9,18,19]. Differentiation between benign and neo plastic lesions is important preoperative. Attenuation is a good indicator of tissue pathology. This parameter can be used to find the type of growth in a tissue as studied earlier[1,2,3,8] and for therapy planning.

5. ACOUSTICAL TECHNIQUES: DEVELOPMENTS

Different types of acoustical techniques are in use, these days, for health care and other applications. Different types of techniques can be electro-acoustic type. Optical type, chemical type and others. The types of sensor systems are classified as follows:

- Piezo-resistive Semiconductor Type Systems
- Piezo-electric / Ultrasonic Systems
- Piezo-Composite Type Sensor Systems
- Bio-Chip-Based Systems
- Electronic Bio-Devices and Systems

- Point-Of-Care Devices and Systems
- U-Health Care Devices and Systems

Mechanical stimuli send signals for many physiological processes for molecular and cellular level actuations., The potential use of focused ultrasound to activate ion channels, in fundamental life science and translational to study the role of mechano-transduction in touch, pain, proprioception, hearing, blood flow, flow sensing in the kidney, and embryonic development

Acoustic technologies are used to activate or inhibit mechanosensitive ion channels of neurons, muscle, or cancer cells, as well as neuromuscular junctions, as a potential treatment for neurological disorders, neurodegenerative diseases, neuromuscular junction disorder, and cancer. This mechanosensitive channel also functions as sonogenetic actuators for future acoustic neuromodulation of targeted cells.

6. INDIAN TECHNOLOGIES

In India, several research and development organisations are actively involved in the basic research and design and fabrication of the sensor-systems.

The work is being taken in the materials research, device fabrication and instrument development.

Technolologies:

- Diagnostic Scammers
  - Scanners (A, B, C, M etc.)
  - Imaging Systems
- Therapeutic Systems
  - Hyperthermia
  - Cell Behaviour
  - Transducer / Sensor Systems
- Safety Standards
  - Tissue Characterisation
  - Tissue Phantoms
  - Safety Limits

*Materials and Sensors

- New Smart Materials
- New Devices / Nano Systems / U-Systems
- Biochips

Artificial intelligence and machine learning are transforming many fields including medicine. In diabetes, robust biosensing technologies and automated insulin delivery therapies to improve health. Learning applications are used in diabetes glucose control to provide an open-source library as a framework for specifying data sets..

AI and in particular ML, are driving discovery across the sciences in engineering, computer science, medicine and the field of diabetes treatment and therapeutics. ML has become particularly important as ubiquitous connected sensors and drug delivery devices are becoming integrated with mobile computing to generate large data sets that can be used to identify patterns that are relevant for improving health outcomes.

7. GLOBAL INNOVATIONS

International compatibility of measurements is important for inter-comparison of physical and mechanical parameters, for better calibration and standardization of measurements[1-26].

Detection

- Nano-sensors
- Carbon nanotubes
- Polymer-based devices
- Biochips, etc.

These are more sensitive and responsive for detection

Therapeutic Treatment

- Nanobiotechnology-based chemotherapy
- New materials like peptides and polymer based DNA are developed for therapy
- Nanoparticles with DNA, for in vivo gene therapy.

The contactless, biocompatible nature of acoustic waves, along with its versatility, excellent spatiotemporal resolution, and a high potential for customization (i.e., many acoustic parameters that can be tuned over a wide working region-operating frequencies from the kHz to GHz range), enable them to become a powerful platform for point-of-care diagnosis. For example, multiple "acoustic tweezers" technologies have been developed to separate bioparticles based on minute differences in their physical properties.

8. FUTURE INNOVATIONS FOR HEALTH CARE

The innovations would see new impact for future research. Imaging and therapeutic systems will be improved further.

The comprehensive analysis dives deep into the top three transformative trends and their profound impact on humanity, technological advancement, maturity, adoption timelines, and real-world market deployment.

- Jonathan Rothberg, an entrepreneur, has big claims for the product to drastically disrupt the biomedical industry,
- The Butterfly iQ, is a cheap handheld ultrasound tool with AI smarts tucked inside. This will 1) revolutionize medical imaging in hospitals and clinics, 2) change the game in global health, and 3) become a consumer product as ubiquitous as the household thermometer.
- The unit cost is estimated as $2,000.

Fig. 6. Chip Product

Fig. 7. Chip Design.

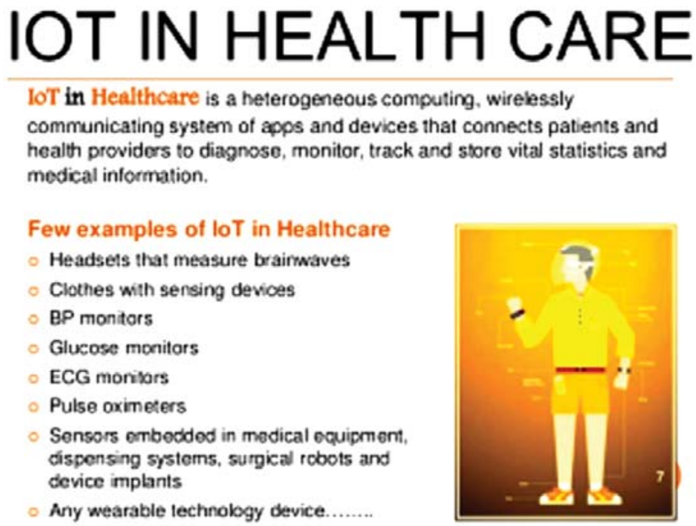

Fig. 8. IOT in Health.

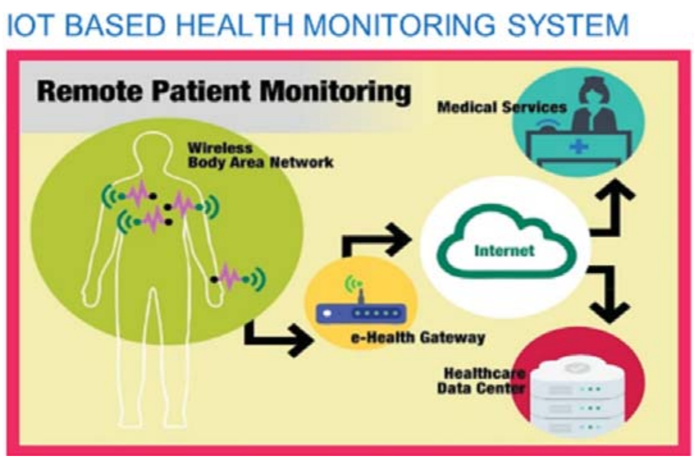

Fig. 9. Remote System

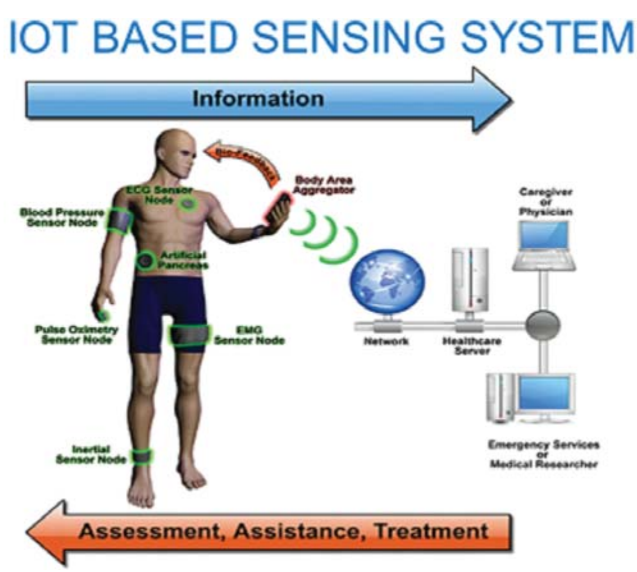

Fig. 10. IOT Sensor

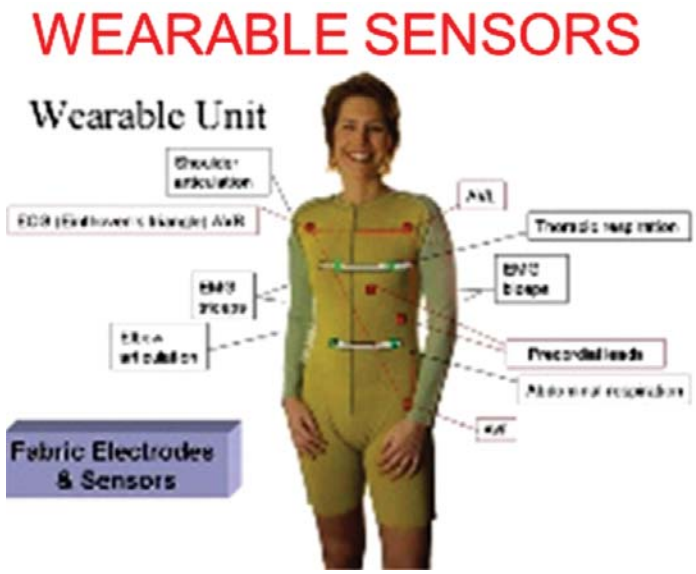

Fig. 11. Wearable System

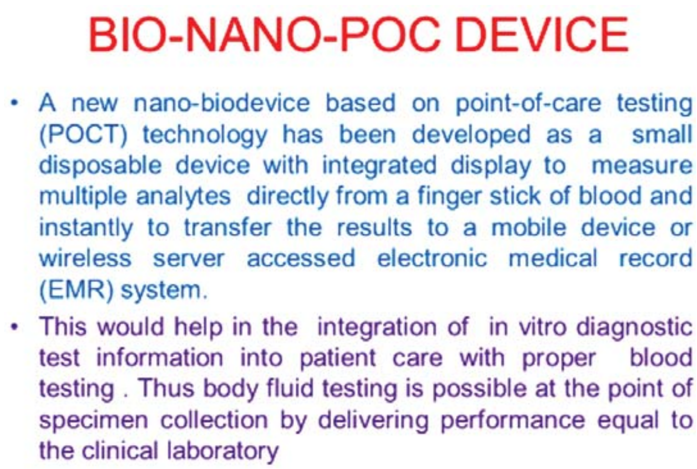

Fig. 12. POC Device

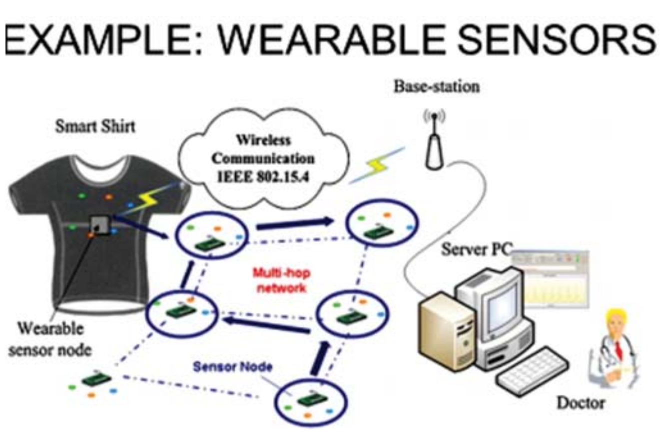

Fig. 13. Wearable Clothes

Fig. 14. Medical Applications

Newly developed acoustic technologies are used in transformational role in life science and biomedical applications in precise biofabrication protocols for tissue engineering and large-scale manufacturing of organoids. Development of future acoustic technologies and their promise in addressing critical challenges in biomedicine is discussed[4-25].

The use of sound has a long history in medicine. Dating back to 350 BC, the ancient Greek physician Hippocrates, regarded as "the father of medicine," devised a diagnostic method for detecting fluid in the lungs by shaking patients by their shoulders and listening to the resulting sounds emanating from their chest1. As acoustic technology has advanced, so too has our ability to "listen" to the body and better understand underlying pathologies.

Acoustic technologies have been developed over the last decade to show their potential in clinical applications.

The future of biomedical acoustics is given in:

i. Acousto Mechano-Biology

ii. Acoustic Systems at molecular level and at Cell Level.

iii. Point-of-Care Diagnostics

iv. *In-vivo* Manipulation

v. Tissue Emgineering

An overview of the four emerging areas of research in (a) developing acoustic technologies for use in biology and medicine including a acoustic mechanobiology, (b) point-of-care diagnostics, (c) biofabrication and tissue engineering, and (d) *in-vivo* acoustic manipulation. Acoustic technologies utilize frequencies spanning the kHz to GHz range, enabling them to manipulate nanometer-sized objects, such as ion channels, at the molecular level and millimeter-sized objects, such as microrobots, at the system level. EVs: extracellular vesicle[4-25].

9. CONCLUSION

Recent developments, local and global innovations are given Future possible research Perspective, challenges, and future directions are discussed, Acoustic technologies for life sciences and medicine have evolved rapidly over the past decade. Four research areas are discussed, t expect (i) improvements to focus acoustic energy, (ii) discovery and delivery, neural activation and inactivation, and cancer therapy. (iii) point-of-care technologies from specialized research labs to hospitals, laboratories, and mobile clinics. (iv) current "chip-in-a-lab" approach of technology demonstration to the fully functional, portable "lab-on-a-chip" approach promised by these exciting technologies.. Thus, advances in acoustics research will provide promising solutions for future life sciences and medical applications search is discussed.

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