Impact Review Analysis & Scope of Noise Pollution for Energy Harvesting

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ABSTRACT

Process of obtaining energy from the environment can be called as energy scavenging or energy harvesting. In this paper, we explore the scope of scavenging electrical energy from the noise pollution present in environment and review various energy harvesting techniques for this purpose. Basically, noise is an unwanted sound that is loud, unpleasant and unexpected. Very high population, industrial, commercial activities and transportation increase the noise pollution level in the environment. In urban areas, transport related noise is the major cause of noise pollution. We know that electricity requirement is increasing day by day. Clean energy resources can help the electricity grid to fulfill the increased requirement without bad consequences. Clean energy does not produce any waste, which can pollute the environment. The various mathematical expressions have shown to minimize the level of noise pollution. With help of empirical formula more electricity can be produced. We reviewed the impact of transportation noise pollution, avoidance methods and simultaneous opportunity to transform it into electrical energy.

Keywords: Energy; Environment; Noise pollution; Energy harvesting; Clean enegy; Transportation noise

INTRODUCTION

In current scenario, noise pollution is increasing rapidly. Increase in the number of vehicles moving on roads is creating more noise specifically in urban areas. The High power machines are used in heavy industries so the sound of machines in these industries creates noise pollution in the surrounding where these industries are established. Rapid increase in the use of machines such as vehicles, home appliances, electronic gadgets etc. is the cause of stress, sleeping disorder, depression and other psychiatrist problems. Robert Koch, A German bacteriologist and Nobel Prize Winner Robert Koch once said "A day will come man will have to fight merciless noise as the worst enemy of health"[Chauhan et al., 2010].

LITERATURE REVIEW

In reference to the sound signals, Frequency is the amount of air pressure change which is measured in hertz (Hz) whereas the measure of loudness (measured in dB) is the change in air pressure resulted from vibrating an object. Larger vibrations lead to the louder sound, called high amplitude and high frequency results in high pitch of sound. Road side traffic noise frequencies commonly range between 700 Hz to 1300 Hz but generally it is considered as 1000 Hz for simplicity[Nguyen et al., 2017]. For the measurement of noise pollution, commonly sound pressure level (SPL) meter is used[Kumar and Kumar, 2018]. Sound pressure level generally denoted as Lp(A) or Leq(A)

where A represents A- weighted filter scheme used in SPL meter. There are three types of frequency weighting schemes named as A, C and Z weighting. In most of the countries A- weighted frequency scheme is used for noise measurement[Kjellberg et al., 1997]. Frequency response of A- weighted filter is similar to the human ear as the lower and upper cut off frequencies of A - weighted scheme are the frequencies that a human cannot hear.

Sound pressure level (SPL) is measured in decibel (dB) and is shown in Equation (1)

$$SPL = 20\log10(P/P_{ref}) \quad\quad\quad (1)$$

Where P= Root mean square (RMS) pressure, And P_{ref}= Reference RMS pressure, at 1000Hz sound frequency, it is given by Pref = 0.00002 Pa.

Table 1. Typical relationship between Sound Pressure and SPL

| S. No.	Sound Pressure (in Pa)	SPL (in dB)
1	0.2	80
2	1	94
3	2	100
4	10	114
5	100	134
6	2000	160

EFFECT OF VEHICULAR NOISE POLLUTION

The vehicular noise contributes the most in total noise pollution and its role is very significant in urban areas. The Traffic noise mainly categorize in four broad categories: Airport noise, Railways noise, Vehicular noise and Seaport noise. [Goswami and Swain, 2017] Road traffic noise mainly includes vehicles on the road and streets like car, motorbike, van, truck buses etc. [Prakash and Veerappa, 2015]Vehicle noise includes sources like Engines, Tires interacting with the road, Sound from the motor parts such as gear boxes, cooling fans, brakes etc and Sounds of cooling fans, gearboxes and brakes, flouting traffic rules[Alam,2011] . In addition to vehicle's noise, high traffic density and various commercial activities in suburban area leads to more noise pollution. [Yildiz, 2007]Noise pollution is considered to be an important parameter to ascertain quality of life in cities. Various surveys are carried out at different locations worldwide to assess environmental noise and related analysis [Banerjee et al., 2008]. Study shows that the noise environment of urban cities in India is aggravating and detrimental to human health surpassing standard noise levels. Table 2 depicts the permitted noise level in few countries and World Health Organisation (WHO) standard. To control the noise pollution, noise mitigation must be done but simultaneously we can work to convert induced noise pollution into electrical energy. Noise from the sources mentioned in Table 3 can be transformed into electrical signal using energy harvesting technique.

Table 2. Acceptable noise level in some countries and World Health Organisation (WHO) standard

Countries	Industrial Area		Commercial Area		Residential Area		Silence Zone	
	Daytime	Night time	Daytime	Night time	Daytime	Night time	Daytime	Night time
WHO	65	65	55	55	55	45	45	35
Australia	55	55	55	45	45	35	45	35
Japan	60	50	60	50	50	40	45	35
US	70	60	60	50	55	45	45	35
India	75	70	65	55	55	45	50	40

Table 3. Sound Power Level of various sources of traffic noise

S. No	Source of traffic noise	Sound Power Level (in dB)
1	Normal street traffic	75
2	Buses, Trucks, motorcycle	80
3	Heavy city traffic, Heavy diesel vehicle	92
4	cars on highway	100
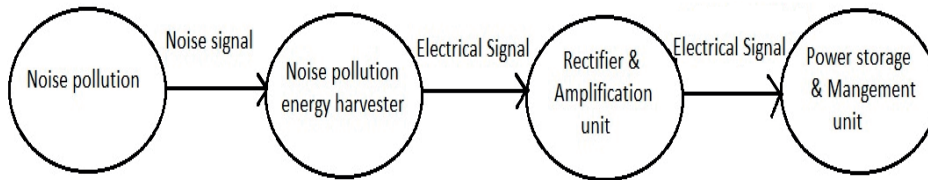
Figure 1. Noise pollution-based energy harvester

METHODOLOGIES

Figure 1 depicts a simple block diagram of noise pollution-based energy harvester. This energy harvester can transform noise pollution into low level electrical signal. The energy harvester can be based on various principles of energy conversion for acoustic signal such as the principle of electromagnetic induction piezo electricity, MEMS (microelectronic-mechanical system), energy harvester and acoustic meta materials[Gammaitoni, 2012], [Jamal et al., 2013],[Cha et al., 2010]. [Amirtharajah and Chandrakasan, 1998],[Meninger et al.] Piezo electric property exhibited by specific materials has extensive potential to generate clean energy from random sound signal for low power application, reducing the energy consumption to some extent. Super capacitors are used for charge storage as it has very high capacitance value and low voltage limits[Salvador et al., 2017]. It can charge the batteries fast but the cost of super capacitor is very high[Liew et al., 2018]. Micro and nano scale noise harvesting suggests that the kinetic energy of micro level is suitable for energy harvesting. MEMS (microelectronic-mechanical system) technology makes possible to design low power self-recharged devices using MEMS devices as electromechanical transducer which converts in the form of variable capacitor which helps to maximize the response of the system[Cha et al., 2010]. This system has been used for remote sensing applications and low power low maintenance digital signal processing and various other biomedical applications. [Li et al., 2014],[Wischke et al., 2011]. An acoustic meta-material, named HRDM (Helmholtz Resonator with built in Decorated Membrane) found capable of performing dual function of sound insulation and energy harvesting both simultaneously. HRDM can provide better sound insulation and efficient strain energy. Table 4 shows the comparison of various principles that are reviewed in cited papers

**Table 4.** Comparative view of various principles of energy harvesting

S. No	Principle	Input applied	Output resulted	Object studied	Applications
1	Electro-magnetic induction	87 dB-90 dB	0.6V - 1.62V	Motor vehicles	Large scale machines, power plants
2	Piezo electricity	97.6 dB (from 78 inch distance)	6.73 V	BaTiO3 Piezo electric transducer	Rechargeable batteries, Walkway at ticket gate
3	MEMS devices	100 dB	50 mV	ZnO nano wires electrodes	Self recharged devices, biomedical application
4	HRMD based Meta-material	1 Pa (sound pressure)	244 nW(with PVDF) 3.33 μ W(with PZT)	Helmholtz Resonator	Low scale devices

PROTOTYPE IMPLEMENTATIONS OF SOUND/NOISE ENERGY HARVESTER

Figure 2 shows a simple one line setup of energy harvesting system. An experimental setup of sound energy harvesting is shown in figure 3[Maruyama, 2020], [Fang et al., 2017]. A wooden box contains loudspeaker and piezoelectric together, providing isolation from atmosphere so that sound signal can be concentrated toward piezo electric. The electrical signal coming through piezo electric after conversion, fed to the CRO, multimeter and SLM (Sound pressure level meter).
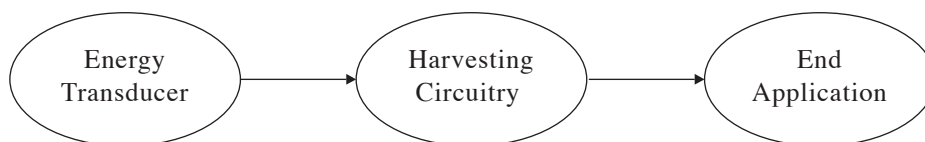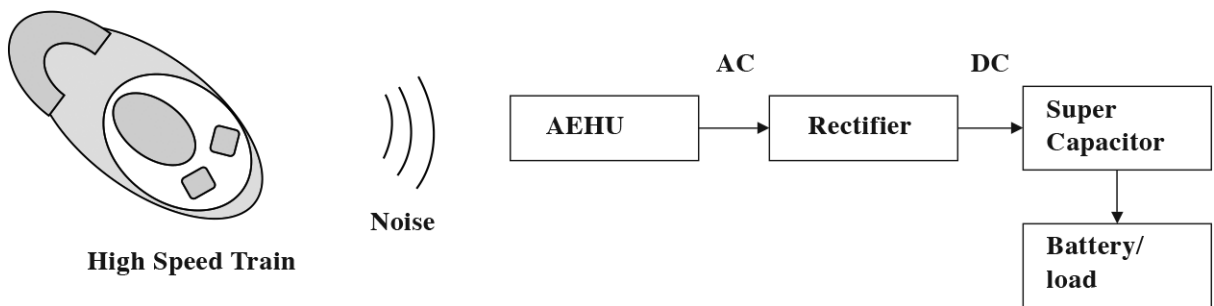

Figure 2. Simple energy harvesting system
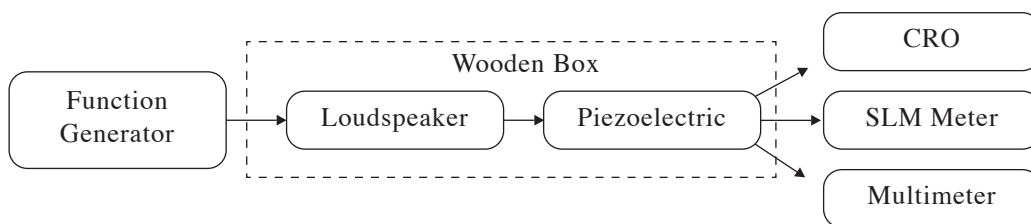
Figure 3. A setup of sound to electrical signal Conversion

A roadway energy harvesting system has been proposed to harvest force exerted on the road due to passing by vehicle's movement is shown in figure 4. Wafer of piezoelectric material are place on the inner layer of the road which converts the exerted pressure into electrical signal then amplified electrical signal further taken to energy management unit by means of electrical wire. Energy storage unit stores the electrical energy that can be further utilized for street lightning purpose. The top layer of the road is made of insulating material provides insulation and safety to the harvester unit place inside[Jiang et al., 2014].
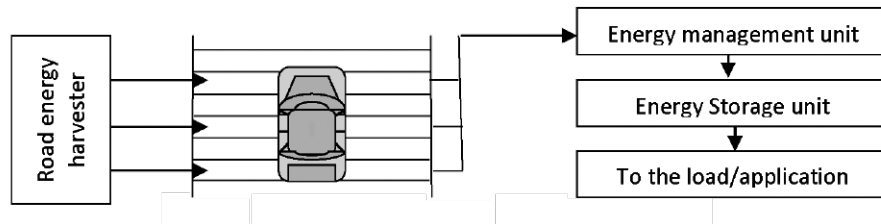
Figure 4. A roadway energy harvesting system

Et. Al Y. Wang proposed a system as shown in Figure 5 and stated that acoustic noise from the high speed train can be converted into electrical signal. AEHU(Acoustic Energy Harvesting Unit) collects the acoustic noise from the passing by trains and converts it in alternating current signal which afterward rectified and get stored in super-capacitor and can be utilized in various applications. The instantaneous output obtained (max.) at 110 dB sound pressure is 74.6mV [Wang et al., 2018].

Figure 5. A noise energy harvesting system for high speed train

NOISE POLLUTION MODELING

Modeling is basically a method to obtain the relation among various variables involved in anyprocess [Subramani and Sivaraj, 2012]. By the means of noise pollution model, one can find the effect and quality of sound and predict noise impact. In recent years, various models have been used to analyse road traffic noise[Verghese et al., 2013], [Kumar et al., 2011]. In some investigations real time data is also accessed by means of sound level meter, velocity meter, temperature sensor, humidity sensor and many other appliances. A general expression of Sound Pressure Level for noise pollution measurement is shown in Equation (2)

$$L_{eq} = A + B log_{10} V \tag{2}$$

Where A and B are constants, and V= Equivalent number of vehicles moving on the road in an hour. [Bilaşco et al., 2017], [Sivaraman et al., 2013]A mathematical model was devised to predict sound pressure level using parameters such as type of road, average vehicle's speed, total vehicle volume/hour, ambient and surface temperature and relative humidity. Other important parameters to calculate level of road traffic are type of road- single / double lane, traffic volume, speed of the traffic, and no. of heavy vehicles in traffic flow. Regression, linear regression and multiple linear regression methods are used to analyze the model [Rajakumara and Mahalinge Gowda, 2009] [Kumar and Jain, 1994]. Along with traffic data obtained, land use data has also taken as independent variable to formulate the model using multiple regression method. Validation of model was done by subtracting observed value of noise level from predicted value of noise level, calculating correlation- coefficient and paired t- test for examining Goodness of fit. Calixto model claims that heavy vehicles generate more noise as compared to light vehicles. Regression analysis based on Calixto model gives good R2 values for Indian conditions when compared to the data collected[Calixto et al., 2003] [Kumar et al., 2011]. The advantage and drawback of sound detection techniques is shown in Table.5

Table 5. Major advantages and drawbacks of sound detection techniques

S. No	Sound detection techniques	Advantages	Drawbacks
1	Normalized filter technique	Simple, less complex, better performance	Not suitable for successive event with very short intervals
2	Median filter Technique	Suitable for continuous detection	Delayed response
3	Thresholding	Fast	Noisy, not suitable for running background
4	Feature Classification	Suitable for background noise with low SNR	-

All around the Globe, researchers are predicting and determining the noise propagation level in different countries[Steele, 2001]. Federal Highway Administration Traffic Noise Model FHWA is the popular software model for traffic noise calculation used in USA, CoRTN (Calculation of Road- Traffic Noise) in UK, ASJ RTN model in Japan and in Germany RLS 90 standard is mainly used. A solid management is carried out in Karachi where lot of waste is created, in the complete process huge amount of noise is generated, after which utilisation of noise is worked in different applications purposes like electricity, mechanical wear[Shaikh and Hussain, 2019].

OPTIMIZATION PROCEDURE

When the noise model is developed and parameters of interest are detected then there comes a requirement of the optimization of the variables. A mathematical process to find out minimum or maximum output by modifying system characteristics is known as optimization procedure[Prakash and Veerappa, 2015]. The most common technique for optimization is meta-heuristic optimization used to search optimal solution of the problem[Cammarata et al., 1995]. There are various procedures of finding optimal solutions for example GA (Genetic Algorithm), Particle Swarm Optimization, Ant Colony Optimization, Hill climbing etcetera[Gao et al., 2019]. Genetic algorithm can optimize the linear and non linear problem used for multi objective optimization for various applications generally using initialization, representation, evaluation, selection, genetic operation and termination steps [Rahmani et al., 2011]

Artificial neural network (ANN): It is an effective method to deal with complex-linear and non linear problems on large scale. A single layer recurrent back propagation (levenberg marquardt) algorithm based ANN model is found to give better performance of predicting noise and minimizes mean square error. Et. Al. V. Nourani presented emotional artificial neural network for road traffic noise which was Artificial intelligence based model and it improved efficiency of predicting traffic noise[Nourani et al., 2020].

HFSP (Hybrid Flow shop Scheduling Problem): It is a new technique to improve the production efficiency and consumption of energy. Noise pollution model is a multi objective problem and it can be expressed as in Equation (3)

$$\text{Min } f(x) = \min[f_1(x), f_2(x), \dots f_n(x)] \tag{3}$$

Where x is solution vector, Let p and q are solution; Solution p can dominate q if and only if $f_i(p) \le f_i(q)$. Using this technique, energy consumption can be minimized but computational time is more than the meta heuristic method[Fu et al., 2020; Sener and Koltun, 2018]..

ANFIS (Adaptive neuro fuzzy inference system): It can be used for modelling heterogeneous traffic condition. It is fuzzy inference system for adaptive networks. Complex traffic model considering various parameters such as driving behavior, variable traffic flow can be modelled and provide comparatively better results. [KumarArora and Vimal Mosahari, 2012] A hybrid adaptive learning control of non linear systems has been proposed. Modelling of environmental noise is a complex and non linear problem that can be achieved by feature selection method and machine learning regression methods [Zhang and Zhang, 2017] [Zhang et al., 1995]. Type of methods are MLP (multi layer perceptron), SMO (Sequential minimal optimisation), GPR(Gaussian process regression). These methods

are considered to be very robust to calculate equivalent sound pressure level. Feature selection methods are to be used along data reduction methods and SMO or GPR to provide best results. The predicted value estimates is shown in Equation (4) as follows

$$y^\wedge = B^\wedge_0 + B^\wedge_1 x_1 + B^\wedge_2 x_2 + \ldots..B^\wedge_n x_n \tag{4}$$

Where x is the variable and B is the constant vector

EXPECTED DESIGN OF OPTIMAL NOISE POLLUTION MOD

Let the noise pollution is expressed as f(x) as shown in Eq.(5) which is optimally minimum is expressed as

$$\text{Objective function} = \min f(x) \tag{5}$$

The function f(x) is subject to constraint as shown in Eq.(6) & (7) with the inequality limits as

$$ax1 + bx2 < c \tag{6}$$

$$dx1 + ex2 < f \tag{7}$$

$$F(x) = \min (f(x) + ax_1 + bx_2 - c_{min} + dx_1 + ex_2 - f_{min})^* C(x) \tag{8}$$

$$\text{where } C(x) = a/f(x) + b/f(x)^2$$

The expression of electricity generation from noise pollution could be of form shown in Equation (8) which includes the combination of Equation (5), (6) & (7) also consider the inequality constraint limit in the equations which is shown in Eq.(8).

APPLICATION

The noise pollution based energy harvester module can be used for charging small batteries, biomedical applications and implantable medical devices such as pacemaker, defibrillator and etc to be implanted inside the human body for diagnosis and treatment of patient which requires rechargeable batteries have might need to be replaced after some time. These implantable units can be self-recharged by itself by the concept of kinetic energy resulted from piezo electric behavior of cardiac and other body parts movement so that the surgery of the patient will not be required for the same. Recently, billboard and sound scrapper have been immerged to help the grid to fulfill the electricity requirement by energy scavenging from the environmental noise pollution. Billboard consists of thousand acoustic sensors which convert urban noise pollution into electricity without being supplemented by city grid for car battery charging and Sound scraper is a modern technology to transform acoustic noise of the urban cities into source of clean energy. The lot of energy efficient solution can be obtained from waste collected from different drainage system & after that well-defined system can be installed for generation of electricity using IOT & artificial intelligence techniques

CONCLUSION

There is a huge potential in noise pollution to generate clean energy. In this paper we have discussed various techniques and methodologies for converting noise pollution into electrical energy. Modelling of noise pollution based energy harvester, analysis methods and optimization procedures are also discussed. Some specific piezo electric material and meta material have potential to harvest acoustic signals efficiently. With the help of suitable rectification, amplification, power management unit and energy storage element this energy can be used for various low power applications. Review of various traffic noise pollution model and optimization techniques are also discussed in this paper.   The relevant design mathematics can be used to limit the noise pollution & new designed empirical formula can be used to get electricity. The optimum electricity conversion from noise pollution can be achieved by using various optimization techniques and intelligent controllers

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