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Application of Nanogenerators-Pzt to Operate Nanodevices: A Noise Energy Survey Analysis Approach

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Abstract: *Due to rapid advancement and growth of electronics and nanotechnology together to produce more sophisticated nano devices which can give satisfactory performance in its operations. A lot of critical research in nanotechnology is being carried out all around the world. A wide range of applications are feasible in real-time using nanotechnology starting from medical to space research. It is going to make a huge impact in our lives. One such application is in the field of scavenging energy from noise. As noise pollution is becoming a great problem in our present day to day lifestyle. So to use this wasted energy in a much more useful manner we perform an analysis of energy extraction feasibility by use of Nanofiber-based piezoelectric devices performance data. We have used various acoustics and energy transfer formulas of these Nano devices to perform mathematical simulation of it, by taking into account real-time noise level survey data sheets. This shows its possibility of using Nano devices with Nanofiber-based piezoelectric devices. Here we have proved its actual practical feasibility from our simulation results.*
Keywords*: Noise Energy, Pollution, Nanogenerator, Sound, Pressure, Intensity, Doppler Effect, Amplitude, Frequency, Nano devices, Energy scavenging, Piezoelectric.*
Abbreviations: *lead zirconate titanate (PZT), Noise Induced Hearing Loss (NIHL), polydimethylsiloxane (PDMS), polyvinylidene fluoride (PVDF), Sound exposure level (SEL).*

I. Introduction:

Nanotechnology is the latest and most versatile field of research. Nanotechnology is defined as the study of manipulating matter on an atomic and molecular scale. It deals with developing devices and structures at a dimension about 1 to 100 nanometer. Nanogenerators are those devices which can harvest mechanical energy using the PZT Nanofibers. Piezoelectric Nano Wire and Nanofiber based generators have potential uses for powering such devices through a conversion of mechanical energy into electrical energy. Throughout the world noise pollution adversely affects the lives of millions of people. Studies have shown that there are direct links between noise and health. Problems related to noise include stress related illnesses, high blood pressure, speech interference, hearing loss, sleep disruption, and lost productivity. Noise Induced Hearing Loss (NIHL) is the most common and often discussed health effect, but research has shown that exposure to constant or high levels of noise can cause countless adverse health effects. (We can see some of these side effects analysis by U.S Environmental protection agency at: www.epa.gov/air/noise.html.). So our motivation comes here. Is there no way to make this noise pollution a boon to society in some way? This can be made possible with Nanotechnology help. Here we want to use the noise energy to operate Nano devices for example nanobots by using some mechanism like converting mechanical pressure (present in noise) to electrical form. This can be done now using piezo-nanofiber (PZT) which is already available or tiny micro piezo-crystals that can convert enough amount of sound energy to electrical form to operate a cluster of nanobots. In our study we have made a simulation of what level of intensity of noise can produce what amount of mechanical pressure by taking into account the some of the governmental survey data available from internet about noise intensity level at various places. These Nano devices can also help control noise pollution by monitoring it in real time.

II. Literature Survey:

Research all around the world are going no to find clean and renewable sources of energy. And noise pollution is a serious problem to the environment and human health. Noise health effects describe problems in both health and behaviour. Unwanted sound (noise) can damage physiological and psychological health. Chronic exposure to noise may cause noise-induced hearing loss. High noise levels can contribute to cardiovascular effects and exposure to moderately high levels during a single eight hour period causes a statistical rise in blood pressure of five to ten points and an increase in stress and vasoconstriction leading to the increased blood pressure noted above as well as to increased incidence of coronary artery disease. A 2005 study by Spanish researchers found that in urban areas households are willing to pay approximately four Euros per decibel per year for noise reduction. An impact of noise on animal life is the reduction of usable habitat that noisy areas may cause, which in the case of endangered species may be part of the path to extinction. Noise pollution has caused the death of certain species of whales that beached themselves after being exposed to the loud sound of military sonar.(reference: http://en.wikipedia.org/wiki/Noise_pollution).

Nanotechnology is making the step towards feasibility of extracting energy from noise with light of recent development in this field of research. Recently Department of Mechanical Engineering, Stevens Institute of Technology, Castle Point on Hudson, Hoboken, New Jersey 07030 and ‡ Princeton Institute for the Science and Technology of Materials (PRISM). They had developed the Nanogenerators that can be used to harness the mechanical energy and convert it into its electrical equivalent form. PZT is a widely used piezoelectric ceramic material with high piezoelectric voltage and dielectric constants, which are the perfect properties for converting the mechanical energy to electrical. PZT can generate much higher voltage and power outputs than other semiconductor types of piezoelectric materials. PZT-nanofibers prepared by an electro spinning process exhibit an extremely high piezoelectric voltage constant (g33, 0.079 Vm/N), high bending flexibility, and high mechanical strength.

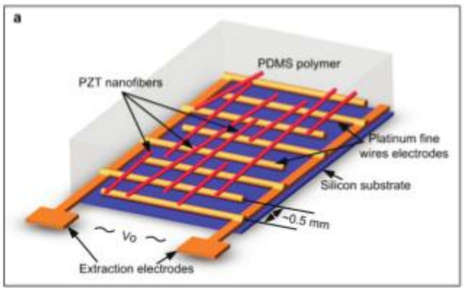

Figure 2.1: Represents a Schematic view of PZT-nanofiber generator (reference paper [4])

The Nanogenerator device fabrication by electro-spinning18 PZT Nanofibers and depositing them on the prepared interdigitated electrodes of platinum fine wire of diameter 50 µm arrays, which were assembled on a silicon substrate. Extracting electrodes are used to extract electrical potential energy. a soft and polymer (polydimethylsiloxane , PDMS) was applied on top of the PZT Nanofibers. The interdigitated electrodes of fine platinum wires were through the PDMS matrix and resulted in charge generation due to the combined tensile and bending stresses in the PZT Nanofibers. A voltage difference between the two adjacent electrodes was thereby induced due to this separation of charge. For a given applied load or impact energy, the maximum output voltage is primarily determined by the piezoelectric voltage constant. Their experimental work to test conversion of mechanical pressure to electrical energy using a free vibrating Teflon cantilever and voltage versus pressure plots shows that it is a efficient Nanogenerator.

Final output voltage is written as follows: (reference paper [4])

$$\Delta V = \int_0^1 g_{33} * E_p \left((sigma_{xx}/E_{11}) - (sigma_{yy}/E_{11})*v - (sigma_{zz}/E_{11})*v\right)*dl \quad \text{(eq-1)}$$

$$Sigma(l) = E_p \left((sigma_{xx}/E_{11}) - (sigma_{yy}/E_{11})*v - (sigma_{zz}/E_{11})*v \quad \text{(eq-2)}$$

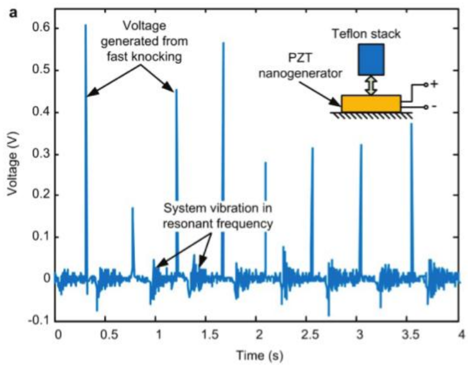

Figure 2.2: One of experimental result plots from (reference paper [4]): The inset in 2.2 shows the schematic of a Teflon stack tapping on the Nanogenerator.

Above figure shows measurements of output voltage from PZT Nanofiber generator. (a) Voltage output measured when a small Teflon stack was used to impart an impulsive load on the top of the PZT Nanofiber generator. This is how Nanogenerator works we studied from the reference paper.

There are also various other nano generators and its uses:

Electrospun PVDF Nanofibers which have high energy efficiency (12.5%) while converting mechanical energy to electrical energy which is even much higher than PZT.(J. Chang et al. ,2012).

There are a lot of flexible Nanogenerators build on polymer substrate. Such as ZnO (Nano Wires) developed using chemical synthesis methods. These piezoelectric based Nanogenerators using ZnO (Nano Wires) arrays on flexible plastic substrate might be able to harvest energy from the environment. Such as body movement (e.g., gestures, respiration, or locomotion). From reference paper: [11], [12], [13], [14].

Applications already developed for PZT:
One of the applications that is developed for use is “A Self Powered PZT Nanofiber Composite Sensor for Structural Health Monitoring” by Xi Chen, Richard Galos and Yong Shi. Describes how by using their device various public structures and buildings can be safeguarded.
After going through various literatures it is clear that we can possibly use noise energy for operating Nano devices. So it might be used at public and high noise pollution causing places.

III. Objectives of this paper:

On the basis of previous work done in this area, the following objectives are set as follows:

a) To study some of the noise pollution level survey data we have collected.
b) To simulate the pressure versus intensity level of noise available for energy extraction and voltage output that is analysed for possible use of nose energy for powering nano-devices.

IV. Scope of this paper:

Here we are trying to set forth that we can make use of noise as a useful energy. As the energy in the noise gets absorbed by Nano devices this can contribute towards controlling the noise pollution, which in turn can be useful to apply in various fields of application in real time. Such as for monitoring the traffic, operating lighting facilities in theatre and monitoring weather conditions etc. As with time the developing cost and commercial manufacturing costs goes down for these Nano devices it will become immensely beneficial to society. We are using the simple acoustic principles to make our simulation study of energy conversion.

V. Method of analysis:

5.1 ***Parameters and threshold used from Acoustic concepts and noise survey:***
Note: Sound power is the cause and sound pressure is the effect.

Difference between sound power and sound pressure:
The sound pressure that we hear is dependent on the distance from the source and the acoustic environment or the sound field in which sound waves are present. This in turn depends on the size of the room and the sound absorption of the surfaces. So by measuring sound pressure we cannot necessarily quantify how much noise a machine makes. We have to find the sound power because this quantity is more or less independent of the environment and is the unique descriptor of the noisiness of a sound source.

Sound:
The mechanical vibrations that can be interpreted as sound are able to travel through all forms of matter: gases, liquids, solids, and plasmas.
Acoustics is the interdisciplinary science that deals with the study of all mechanical waves.
Without a specified reference sound pressure, a value expressed in decibels cannot represent a sound pressure level.

The atmospheric pressure is not same as the sound pressure. The standard atmospheric pressure:

$$101{,}325\ Pascal = 1{,}013.25\ hPa = 101.325\ kPa.$$
$$1{,}000{,}000\ \mu Pa = 1\ Pa = 1\ N/m^2 \equiv 94\ dBSPL\ and\ 1\ bar = 10^5\ Pa$$
$$1\ kPa = 10^3\ Pa = 1000\ Pa = 1{,}000\ N/m^2 \equiv 154\ dBSPL$$

Since the sound intensity level is difficult to measure, it is common to use sound pressure level measured in decibels instead. Doubling the Sound Pressure will raise the Sound Pressure Level by 6 dB. Sound level is the sound pressure level in decibel (SPL). Sometimes the acoustic intensity level −5 in dB (SIL). The reference sound pressure is p0 = 20 μPa = 2 × 10^{-5} Pa. The reference sound intensity is I = 10^{-12} W/m^2. Sound intensity is directly proportional to square of sound Pressure ($I \sim P^2$). Sound pressure p is a “sound field quantity” and sound intensity I is a “sound energy quantity”. The sound pressure is the alternating sound pressure called as RMS value. The sound pressure amplitude is the peak value of the sound pressure. The sound volume (loudness) is determined mostly by the sound pressure p and expressed as sound pressure level L_p in dB.

$$L_p = 20\ log_{10}\ (P/P_o)\ in\ dB = L_I = 10\ log_{10}\ (I/I_o)\ in\ dB \quad \text{(eq-3)}$$

The sound intensity is a sound energy quantity and sound pressure is a sounud field quantity.
Some other critical properties of sound:
Sound waves propagate its energy in two-dimensional or three-dimensional medium. The intensity of the sound wave decreases with increasing distance from the source. The decrease in intensity with increasing distance by

Doppler Effect methods that means that it spreads away in circular (two-dimensional) or a spherical order (three-dimensional) surface and thus the energy of the sound wave is being distributed over a greater surface area. Since energy is conserved and the area through which this energy is transported is increasing, the power (being a quantity that is measured on a per area basis) must decrease. The mathematical relationship between intensity and distance is sometimes referred to as an inverse square relationship. The intensity varies inversely with the square of the distance from the source. So if the distance from the source is doubled (increased by a factor of 2) then the intensity is quartered (decreased by a factor of 4). Since the intensity-distance relationship is an inverse relationship, an increase in one quantity corresponds to a decrease in the other quantity. And since the intensity-distance relationship is an inverse square relationship, whatever factor by which the distance is increased, the intensity is decreased by a factor equal to the square of the distance change factor.

Intensity = power / area

$$I = P/A = P/(4\pi r^2) \qquad \text{(eq-4)}$$

Noise survey (data of Airport) parameters used in our study are:

A number of variables are used to describe sound; it includes amplitude (loudness), frequency (pitch) and duration.

a. **Amplitude:**
   It is measured in dB. And a 10 dB increase in amplitude seems twice as loud to listener. Amplitude is measured with the help of a sound level meter which has a dB scale.
b. **Frequency:**
   It is measured in cycles per second or Hertz (Hz). Sounds with energy concentration between 2,000 Hz and 8,000 Hz are perceived to be louder than sounds of equal sound pressure level at lower frequencies. So scientists have developed an A-weighted scale that reduces the relative weighting of lower frequency sounds in the overall weighted measure. This measurement of sound, referred to as dBA, is the standard established by the FAA for FAR Part 150 Noise Studies.
c. **Duration:**
   A final characteristic of sound is its duration, or how long it lasts at a particular location.

Airport's noisy environment consists of a series of individual aircrafts operations including arrivals, departures, taxiing, over flights and engine start-ups. They described it in their survey using three noise metrics.

- Sound exposure level (SEL)
- Equivalent sound level (L_{eq})
- Day-Night average sound level

Sound exposure level (SEL):

According to survey paper Sound Exposure Level is a measure of the A-weighted total sound energy of a single noise event, such as an aircraft flyover, represented as the A-weighted decibel level of that event including its intensity, frequency, and duration. This measure is normalized to reference duration of one second so that noise events of different duration's can be compared. This is measured in (dBA).

Equivalent sound level (L_{eq}):

The single value of sound level calculated for a given period of time is the L_{eq}. This metric is A-weighted and it accounts for all of the sound energy occurring during a particular period of time (i.e., one minute, one hour, one day, etc.). L_{eq} is used to find the average noise over a period of time.

We are not going to consider Day-night average sound level in our study. We are going to use this A-weighted scale sound level as input to our simulation plots. Because Sound exposure level is ideal to find the energy we can obtain from sound in real time.

Now we will make some assumptions regarding the formula used for voltage to stress relation in this Paper by replacing stress with pressure for our calculation of PZT output voltage. So our formula becomes:

$$V = g_{33} * P \qquad \text{(eq-5)}$$

Here g_{33} =0.079 Vm/N (PZT voltage constant) and P represents the pressure obtained from sound intensity calculation.

5.2 *Simulation plots using Acoustic concepts and noise survey:*

Data sets used for our plot: Because most of the survey noise level lies in this range which we observed from our literature survey.

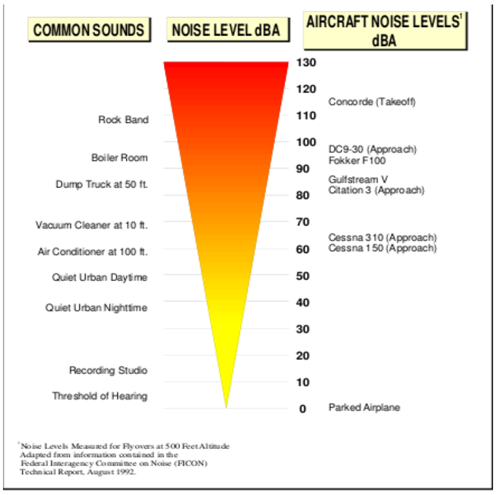

Figure 5.2.1: Represents A-weighted scale sound levels (from survey paper [6])

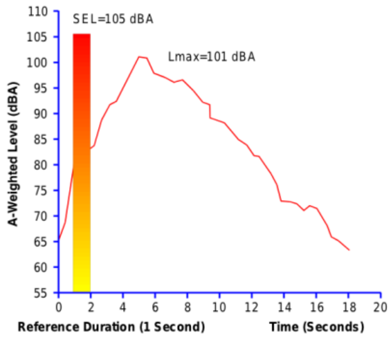

Figure.5.2.2: Represents the Sound exposure level (from survey paper [6])

Using the above data set we will perform our simulation for Analysis.

a. Low noise intensity level plots and its Analysis : (55-105 dBA):

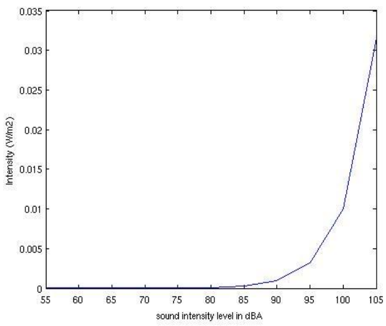

Figure 5.2.3 (a): Represents the power relation plot

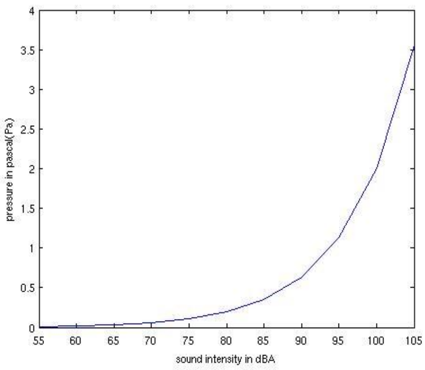

Figure 5.2.3 (b): Represent the force relation plot

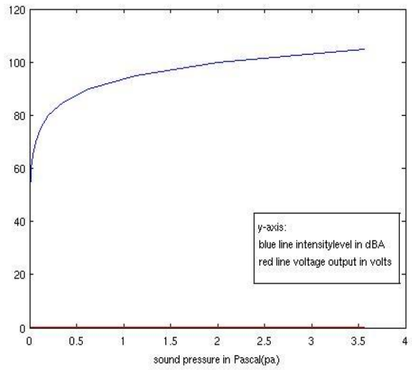

Figure 5.2.3 (c): Represents Input to Output comparison plot

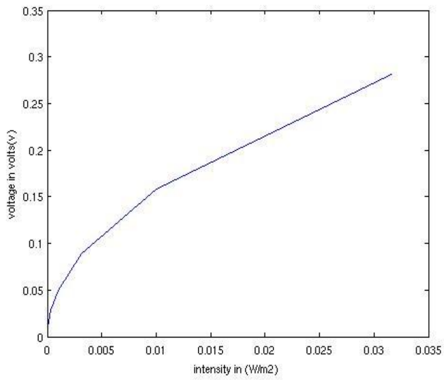

Figure 5.2.3 (d): output efficiency with respect to power

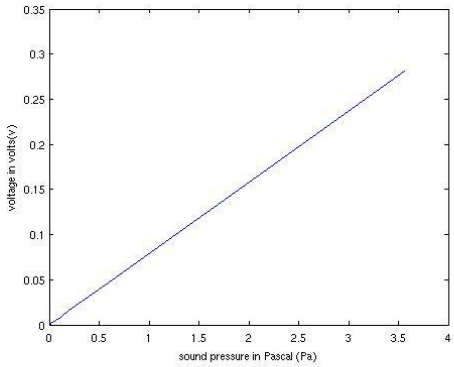

Figure 5.2.3 (e): output efficiency with respect to force

These plots are done for the analysis of possibility of application of PZT in the general noise intensity level conditions which ranges between 55-110 dBA at public places.

The first two plots 5.2.3(a) and 5.2.3(b) represents the relation between the noise level intensity to the actual intensity which is used for power and noise intensity level to pressure which in turn is used for force applied to PZT nanofibers respectively.

Then in Figure 5.2.3(c) we see how the input noise intensity level and the output voltage from PZT are related with respect to Pressure. This shows that as the noise intensity level increases remarkably still the output voltage change is not so significant with respect to pressure. Still then also there is a chance we can obtain sufficient energy to operate Nano-devices. As these Nano devices requires feeble amount of voltage to operate.

Similarly these Figure 5.2.3(d) and 5.2.3(e) are used to show the response of PZT (output voltage) to the intensity and pressure respectively.

b. High noise intensity level plots and its Analysis: (110-130 dBA):

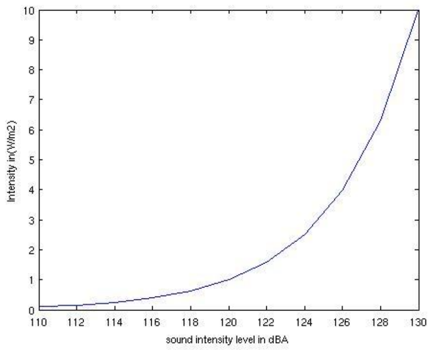

Figure 5.2.4 (a): Represents the power relation plot

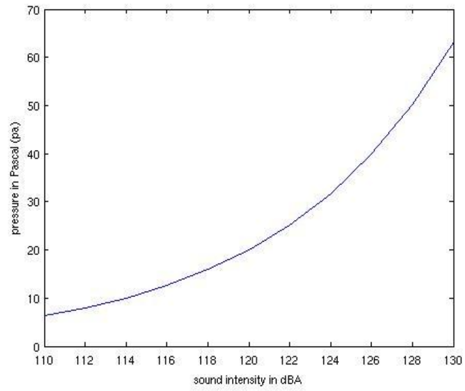

Figure 5.2.4 (b): Represents the force relation plot

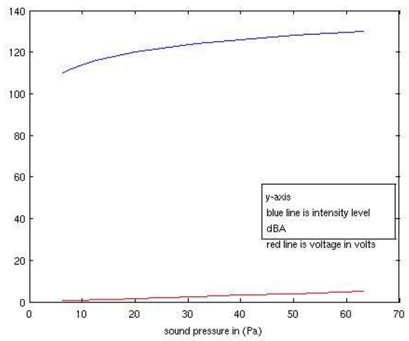

Figure 5.2.4(c): Represents Input to Output comparison plot

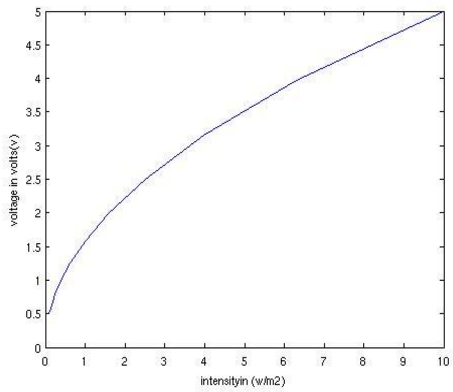

Figure 5.2.4(d): output efficiency with respect to power

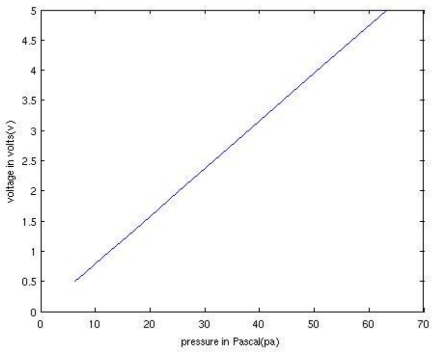

Figure 5.2.4 (e): output efficiency with respect to force

Analysis here is similar to previous case. We plotted it because we want to show that noise intensity level source of this high value can provide better amount of energy for operating Nano devices at these very noisy location such as airport and cinema theatre. Which is clear from output plot (figure: 5.2.4(c)).

5.3 *Artifacts in our simulation:*

One main limitation in our simulation is that we are not able to get hold of real time data about how much in actual can the PZT convert the mechanical pressure to electrical energy. And our assumption of stress as pressure for calculation of voltage limits our accuracy of result.

VI. Salient features of this paper

In this paper we have tried to show the possibility of application of noise as a useful energy in the day to day life. We noted from our observations of results in our simulation it is quite possible to harvest the noise as a useful energy to operate Nano devices using PZT Nanofiber Nanogenerator. We also observed that noise intensity level at high noise level places can be a good source of energy. And we saw that sufficient voltage can be generated from noise from average level of noisy places. This noise can also be a source of kinetic vibration energy. It is more suitable for a larger variety of applications for environmental monitoring or even biomedical problems (Adriano IEEE CIMCA (2006)). It is also possible to use this kinetic vibration energy to operate Nanomotors having Naocoil and Nanoelectromagnet which work on the principle of mutual induction.

VII. Conclusion and scope of future work

In this paper we try to show that noise can also be a good source to operate Nanodevices. And our work shows a better chance of using the noise energy as a good source for application of Nanogenerator to operate Nanodevices. As the efficiency and sensitivity of the PZT Nanofiber Nanogenerator improves the possible scope of application at public noisy places increases. It can be used to monitor traffic, weather and public safety systems etc. Some more improvements can be done to our work by using more accurate formulas for obtaining the mechanical to electrical energy conversion by PZT Nanofiber.

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