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Conversion of Roadway Noise to Electrical Energy: An Innovative Approach for Sustainable Energy Generation

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ABSTRACT

Roadway noise is the collective sound energy emanating from motor vehicles. It consists chiefly on road surfaces, tire, engine/transmission, aerodynamic, and braking elements. Noise of rolling tires driving on pavement is found to be the biggest contributor of highway noise and increases with higher vehicle speeds. This study explores the use of a rather unconventional form of energy (Sound). An application is proposed for the same in which a distinctly designed circuitry is used to convert the sound produced by a loudspeaker. Based on the law of electromagnetic induction, the vibrations produced by the speaker can be converted into electrical energy. The use of sound energy is both clean and unconventional. It is an entire paradigm shift from the concept of noise cancellation to a new idea of noise utilization. This paper takes a step forward in this direction, using sound as a source of energy to provide a viable electronic source in a vehicle, converting the sound waves into electrical energy indicator used to power streetlight. The result of this study shows the relationship between the spring displacement and the DC voltage generated, and the relationship between the sound source and the generated voltage. It follows that the relationship is directly proportional, and a 95 dB sound generated of 1.3V, which is regulated by using an XL4016 8A regulator to maintain a constant voltage of 2V required to lighten the LED indicator used to power the prototype streetlight implemented in this study.

1. INTRODUCTION

Energy is forever going to be a prominent subject across the globe. Billions of dollars have been plunged into the industry to help develop a sustainable system for the generation of electricity; researching multiple methods for the system, and we now have multiple means of generation of electricity [1]. From hydro-powered which runs based on the use of falling water to the use of fuel to boil water and turn it to hot steam to drive the turbine, to the use of hot gases (Gas turbines) to generate electricity, etc. Today, technologicalstrides and advancements have been witnessed in the energy sector. However, there is still an "energy problem". In many countries, there are different categories of people in terms of the energy consumed. There are the unreached – those who do not have access to electric supply; there are the underreached – those who do not have sufficient electrical energy and there are the reached – those who have sufficient energy [2]. Hence, the reason why energy will always be a factor to ponder on.

The need for alternative energy is rising fast. Most of the power produced in the world is hinged on the availability of fossil fuels. Power consumption is an ever-growing need that requires urgent attention. Sound as an alternative source of energy has a huge potential that has been left largely untapped as we progress further towards using Renewable and sustainable sources of energy.

The exploitation of alternate sources of energy is essential in ensuring we have sufficient electricity for the world's ever-growing populace. This is the foundation on which this study is built. How do we do all we can in ensuring there is enough electricity supply for the present generation and the future?

Sound is a ubiquitous part of the world, it is everywhere from the engine room of industry to the darkness of a deep underground cavern [3]. Sound is a form of energy and from the first law of thermodynamics, energy can neither be created nor destroyed but can be transformed from one form to another. So, theoretically, sound can be converted into electricity. This is the theoretical foundation of the exploitation of sound to use as an alternate source for the generation of electricity.

Numerous authors have attempted to convert sound to electrical energy, the noise pollution in the road would be able to convert into electric energy and lights the street lightning, traffic signals and various other electrical appliances. Firstly, the oscillation-producing sound wave might be converted into electricity [4, 5]. However, its disadvantage is that efficiency will only be attained when it uses loud machinery, such as in nuclear power plants and other businesses with large, distracting machines. The thermoelectric effect states that a temperature rise in a conducting material causes heat flow, which causes the dispersion of charge carriers. Deji observed that electricity may generate between two different conductors at the heat of this effect. A potential difference is then produced by the movement of charge carriers between the hot and cold areas. The second technique involves transforming the sound energy into heat energy. The particle of the medium will be interrupted by the sound energy as it travels, and these disruptions will be exploited to convert the sound energy into heat energy. As more energy will be lost during the conversion of sound energy to heat energy, the approach is less efficient. The third method involves using piezoelectric materials to convert sound energy to electrical energy. When the direction of the strain changes, the polarity of the electric charge also changes. When certain single crystal materials are distorted by the application of peripheral stress, which causes electric charges to develop on the crystal surfaces, several situations take place [6, 7]. The crystals that display it are referred to as piezoelectric crystals, and this phenomenon is known as the direct piezoelectric effect. However, due to generational issues, using piezoelectric materials is costly and impractical. Additionally, because a piezoelectric transducer operates with a tiny electric charge and has a low output and is sensitive to changes in temperature and relative humidity, an external circuit must be connected to it [8]. However, in all their findings, their system could not be used in the places where decibel of sound is very low. Sound is essentially vibration propagated as an acoustic wave [9]. In the conversion of sound to electricity, it is important to discuss vibrations, what they are, how they are propagated, and how they can be harnessed to produce sufficient electricity supply. Sounds and vibrations are closely related, so in the exploitation of sound, it is imperative to dive deep into the study of vibrations.

Sound, or pressure waves, are generated by vibrating structures (e.g., vocal cords, car horns); these pressure waves can also induce the vibration of structures (e.g., eardrum). Hence, attempts to reduce noise are often related to issues of vibration.The vibration of a physical body typically involves the transfer of potential energy into kinetic energy and vice-versa, alternatively.

2. METHODOLOGY

The methodology of this study is based on the principle of a speaker and a microphone. The speaker essentially does the reverse of the microphone which is to absorb sound. The speaker emits sound and amplifies it while the microphone only receives the sound. The operation of the speaker is rather straightforward and simple for anyone who is familiar with Faraday's Law of Electromagnetic induction. Eventhough, it is a witty invention, but it is nevertheless premised on this fundamental law. There are four essential components of the speaker, and after stating the design is premised on Faraday's law of Electromagnetic induction, it can be easily inferred that two of those must be the magnet and the conduction coil. The key components are the voice coil (conduction coil), diaphragm, spider, and the magnet. There are other components of a speaker, but these few are the key components of the speaker. Other components include pole plates, dust cap, cone, dust cap and surround as shown in Figure 1.

2.1 Sound generation and distance calculation

Sound is essentially pressure waves receding from a source [10, 11]. One fundamental problem in harnessing sound is how much of its intensity is lost in a short distance. Considering the human ear as the receptor here, the relationship between the intensity of sound and the area of the receptor is given in the equation below.

$$Intensity = \frac{\text{Power}}{\text{Area}} \tag{1}$$

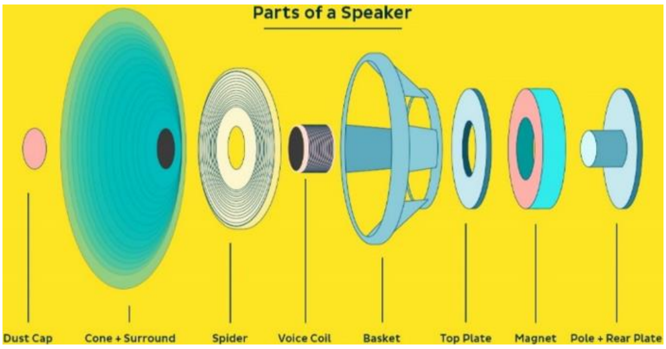

Figure 1. Diagram of the parts of a speaker

Considering the human ears to be spherical, the area of the receptor therefore will assume that of a sphere [12], i.e.,

$$Area = 4\pi r^2 \tag{2}$$

Upon observation of the above equations, it can be deduced that the intensity of sound is inversely related to the square of the distance, i.e.,

$$I \propto {}^{1}/_{R^2} \tag{3}$$

Therefore, it can be further deduced that if the distance is doubled, the intensity of the sound is going to be one-fourth of its value. The following equation gives the relationship between the sound level, which is measured in Decibels, and the intensity of the sound [13].

$$\beta = 10\, log\left(\frac{I}{I_0}\right) \tag{4}$$

where,
β is the sound level.
I is the intensity of sound.
I_0=10^{-12} W/m^2 is the threshold intensity of hearing.

2.2 Design approach

The theoretical foundation is Faraday's Law of Electromagnetic Induction [14]. This provided the foundation and launch pad on which the study is built upon. In the conversion of sound to electricity, the volatility of sound is an important consideration. This means sounds are very volatile which means much of their energy is wasted if not harnessed properly. This also poses another difficulty – how to efficiently harness the sound from its source? In solving the highlighted problem, the study focused on certain parts on which it is believed to be possible to change. Such included sound absorption and sound amplification. In focusing on these two terms, the study is considered presentable. This was done by employing different components. The enforcement of this study includes three major segments:

Pre-amp Circuit: The regulator to be used in this set-up is an XL4016 8A regulator. This is because the battery rating ranges between 7.2v- 8v. The regulator uses a combination of capacitors and diodes for the conversion process. So, in essence, the regulator does two things: it converts the AC signal coming from the transformer to DC and maintains an output voltage of 2v needed to power the LED lights.

Power Amplifier (Transformer): The received signal was stepped up using a transformer. The step-up transformer has a primary-to-secondary turns ratio of about 1:50. Four 1N5822 diodes are used to rectify the input voltage and electrolytic capacitors will be used to filter the output voltage and for energy storage.

Power Storage: The amplified output from the Op Amp will travel to the input terminal of the BJT transistor which will acts as a switch. The output from the transistor will be fed to a 555 timer. The 555 timer will receive the output from the transistor and hold the charge for some time before feeding it to LED indicator.

The speakers serve as the sound absorption device, which makes its function in this case inverted, this was done because the speakers in this set up functions as a transducer [15]. The speakers contain magnets and coils, as vibrations hit the diaphragm of the speaker, there is a back-and-forth movement, and in the presence of a magnetic field electricity is generated. This way the function of the speaker is inverted from generating sound from electricity to generating electricity from sound (vibrations). The sound generation process is shown in Figure 2, while the electrical wiring of the system and the Isometric view of the developed prototype system is shown in Figure 3 and Figure 4.

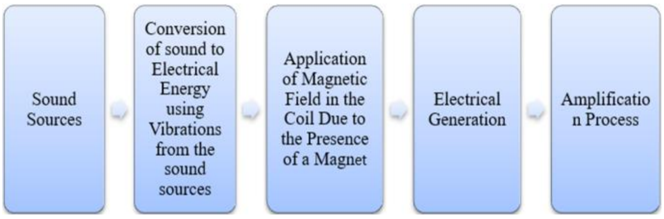

Figure 2. Block diagram of the process for electrical power from a noise source

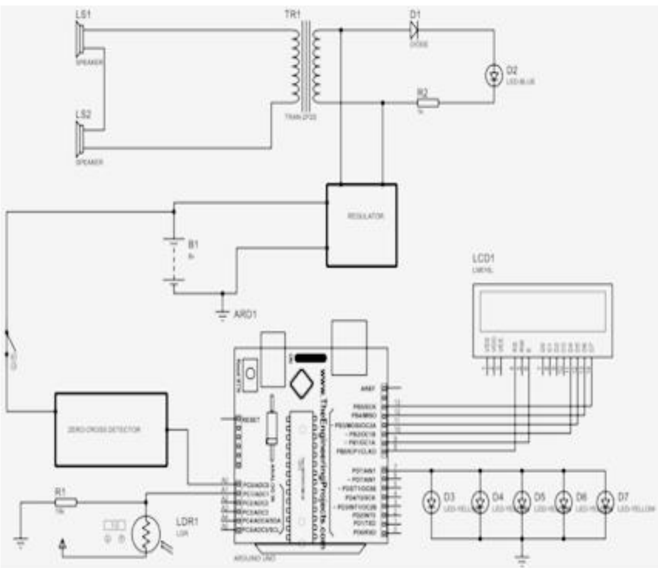

Figure 3. The electrical diagram of the system

The purpose of the Arduino uno in this set-up is to configure the streetlight to be somewhat smart. It does this with the help of an LDR (Light Dependent Resistor). A set of codes were written and uploaded onto the Arduino Uno to achieve this. This makes the streetlight turn on during dark hours and off otherwise. This helps to eliminate redundant labor that could be otherwise redirected to something more enterprising.

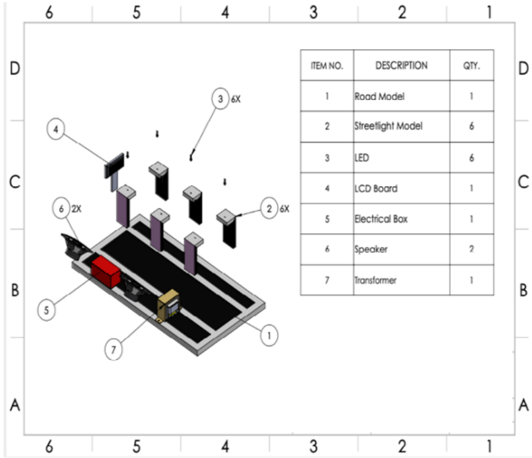

Figure 4. Isometric view of the developed system

The Arduino Uno also functions to program the display on the LCD. The LCD displays the voltage level of the battery, and its intensity. An abstract of the programming area is shown in Figure 5.

Figure 5. A snapshot of the arduino uno integrated development environment

3. RESULT AND DISCUSSION

Upon completion of the physical system as shown in Figure 6, it was imperative to test the project and get results. This was necessary to generate an overview of how the system will behave under different conditions.

To do this, a spring was used to create sound and induce vibration in the diaphragm of the speaker thereby producing electricity as per Faraday's Law of Electromagnetic Induction as shown in Figure 6, where two speakers were placed close to the system. Electricity generated from this sound would be stored in the 8v battery, which will be used by the LED indicator. A suitable spring was selected for the study and the spring constant was determined by using Hooke's law experiment. The tabulated results are displayed in Table 1.

Figure 6. A prototype of the developed system

Table 1. The results of the Hooke's law experiment performed on the spring

S/N	Force (N)	Spring Displacement (m)
1	1	0.002
2	2	0.009
3	3	0.007
4	4	0.009
5	5	0.01

The values were used to construct a graph as shown in Figure 7. The length of the spring used was 0.008 meters and the equation used to determine the spring constant is shown in Eq. (5).

$$F=-ke \tag{5}$$

where,
k is the spring constant.
e is the spring displacement.
F is the force.

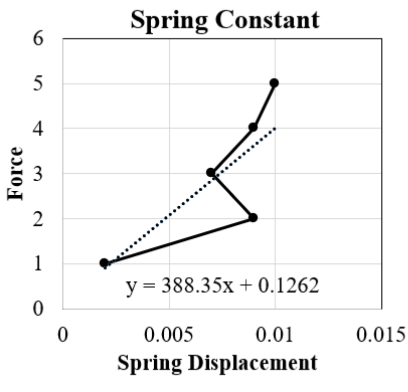

Figure 7. A graph showing the force against spring displacement

The spring constant was then determined using the trend line and the equation of a straight line [16].

$$y=mx+c \tag{6}$$

where, *y* represents the force generated by the spring and *m* is the slope of the graph, which may be calculated as:

$$m = \frac{Change\ in\ Force}{Change\ in\ Spring\ Displacement} \tag{7}$$

From the graph, the slope and spring constant, k was determined to be 388.35 N/m. It is important to note also that a linear trendline was selected as opposed to polynomial, power, logarithmic, exponential and moving average, because it was the most suitable. The spring constant was then used to determine the force as the spring was made to extend and induce vibration in the diaphragm of the speakers, thereby producing voltage. The DC voltage were measured against the Force and the spring displacement as shown in Table 1 and Figure 8.

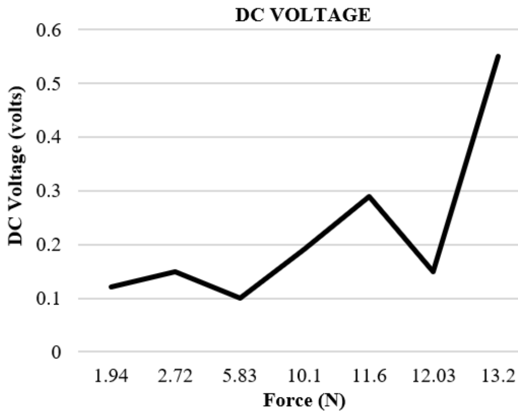

Figure 8. A graph showing the relationship between force induced and DC voltage generated

The voltage drop across the coil was measured using a digital multimeter in volts (V), and sound was measured using a sound meter in decibels (dB) close to the source. To increase the voltage produced across the coil, a transformer was utilized. When the speaker made an 80 dB sound, the system generated a voltage of 0.5V, but when it made a 95 dB sound, it created a voltage of 1.3V. The voltages are regulated by using an XL4016 8A regulator to maintain a constant voltage of 2v required to lighten the LED indicator that serves as the prototype streetlight implemented in this study.

4. CONCLUSION

The study succeeded in demonstrating that sound can be converted into electricity and used for a suitable process, i.e, powering a smart streetlight. The noise generated from roadway vehicles was converted to acoustic energy. The result of this study was presented in detail, which shows the relationship between the spring displacement and the DC voltage generated, and the relationship between the Force of the spring and the DC voltage generated. It follows that the relationship is directly proportional, and a vibratory system can generate a certain amount of electricity based on its property (in this case a spring with spring constant 388.35N). When the speaker made an 80 dB sound, the system generated a voltage of 0.5V, but when it made a 95 dB sound, it created a voltage of 1.3V. To achieve high efficiency of this system, the system should be placed very close to the sound source, as higher sound produces higher voltage. Furthermore, a piezoelectric device connected directly to a condenser microphone has not been found suitable in this research, which are affected by temperature variations and relative humidiy.

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