

## Piezo Electric Energy Harvesting

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**Abstract:** Energy Harvesting systems are used to harvest the normally lost environmental energy and to convert it into electrical energy. This approach can be attractive where batteries are a bottleneck for the whole system (e.g. they have a finite life time and their replacement or recharge is not feasible or too expensive). An energy scavenging system, instead, is a theoretically endless energy source. In literature many papers describe methodologies to realize the energy-scavenger. A lot of them focus on the conversion of the energy associated to mechanical vibrations since they can be easily found in many environments. Piezoelectric materials (PZT) can be used as mechanisms to transfer ambient vibrations into electrical energy that can be stored and used to power other devices.

**Keywords:** Piezo cells, mechanical force, energy harvesting, ambient.

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### I. INTRODUCTION

Energy harvesting has been a topic of discussion and research since three decades. With the ever increasing and demanding energy needs, unearthing and exploiting more and more energy sources has become a need of the day. The field of power harvesting has experienced significant growth over the past few years due to the ever-increasing desire to produce portable and wireless electronics with extended lifespan. Current portable and wireless devices must be designed to include electrochemical batteries as the power source. The use of batteries can be troublesome due to their limited lifespan, thus necessitating their periodic replacement. In the case of wireless sensors that are to be placed in remote locations, the sensor must be easily accessible or of a disposable nature to allow the device to function over extended periods of time. Energy scavenging devices are designed to capture the ambient energy surrounding the electronics and convert it into usable electrical energy. The concept of power harvesting works towards developing self-powered devices that do not require replaceable power supplies. A number of sources of harvestable ambient energy exist, including waste heat, vibration, electromagnetic waves, wind, flowing water, and solar energy. While each of these sources of energy can be effectively used to power remote sensors, the structural and biological communities have placed an emphasis on scavenging vibration energy with piezoelectric materials [5]. Energy harvesting is the process by which energy is derived from external sources and utilized to drive the machines directly, or the energy is captured and stored for future use. Then later in the report, we have proposed the idea of combining energy from a number of piezoelectric cells to obtain higher voltages. Piezoelectric cells can be utilized to obtain voltages of very small values and hence can drive low voltage devices i.e. using this Piezo cells electrical energy can be generate by converting the applied mechanical force into electrical energy and storing that produced energy for its later use. Hence, Piezoelectric Energy Harvesting comes under the category of Micro scale energy harvesting scheme. The piezoelectric effect is a reversible process\_in that materials exhibiting the direct piezoelectric effect (the internal generation of electrical charge resulting from an applied mechanical force) also exhibit the reverse piezoelectric effect (the internal generation of a mechanical strain resulting from an applied electrical field).

### II. BACKGROUND

Earlier or rather we can say currently there is no technique to harvest energy i.e. electrical energy which is continuously used by the tunnels for train. Even if the train is not inside the tunnel, lights of the tunnel are always on, thus this makes the unnecessary use or waste of electricity, and thus we have proposed our system to overcome this unnecessary waste of electricity. Apart from our proposed energy harvesting technique there are various energy harvesting techniques are used but these techniques causes harm to nature or overall environment cycle, thus to overcome all these demerits and constraints of the energy harvesting techniques, concept of energy harvesting technique for the lights inside tunnels is discussed in this paper i.e. Piezo electric energy harvesting.

### III. LITERATURE SURVEY

#### 1.1 What is Energy harvesting?

Power harvesting, energy harvesting, power scavenging, and energy scavenging are four terms commonly used to describe the process of extracting useful electrical energy from other ambient energy sources using special materials called transducers that have the ability to convert one form of energy into another. While the words power and energy have vastly different definitions, the terms "power harvesting" and "energy harvesting" are used interchangeably throughout much of the literature to describe the same process of extracting electrical energy from ambient sources. Even though most of the energy coupling materials currently available have been around for decades, their use for the specific purpose of power harvesting has not been thoroughly examined until recently, when the power requirements of many electronic devices has reduced drastically[7]. Energy harvesting can be obtained from different energy sources, such as mechanical vibrations, electromagnetic sources, light, acoustic, airflow, heat, and temperature variations. Energy harvesting, in general, is the conversion of ambient energy like natural energy, human energy, mechanical energy, light energy etc into usable electrical energy. When compared with energy stored in common storage elements, such as batteries, capacitors, and the like, the environment represents a relatively infinite source of available energy. Ambient energy harvesting is also known as energy scavenging or power harvesting, and it is the process where energy is obtained from the environment. A variety of techniques are available for energy scavenging, including solar and wind powers, ocean waves,

piezoelectricity, thermoelectricity, and physical motions. For example, some systems convert random motions, including ocean waves, into useful electrical energy that can be used by oceanographic monitoring wireless sensor nodes for autonomous surveillance. Ambient energy sources are classified as energy reservoirs, power distribution methods, or power-scavenging methods, which may enable portable or wireless systems to be completely battery independent and self sustaining [6].

1.1.1 A general overview of ambient energy sources are presented, and summarized the resources according to their characteristics:

1.1.1.1 Human Body:

Energy can also be produced through various human actions such energy can be stored and used for various applications. Mechanical and thermal (heat variations) energy can be generated from a human or animal body by actions such as walking and running.

1.1.1.2 Natural Energy:

Energy sources for natural energy are available. They are finite in nature. But they are pollutant. Ex. Wind, water flow from waterfall, sea/ocean waves, and solar energy can provide energy from the Environment.

1.1.1.3 Mechanical Energy:

Vibrations from machines, mechanical stress, and strain from high-pressure motors, manufacturing machines, and waste rotations can be captured and used as ambient mechanical energy sources.

1.1.1.4 Thermal Energy:

Waste heat energy variations from furnaces, heaters, and friction sources.

1.1.1.5 Light Energy:

This source can be divided into two categories of energy: indoor room light and outdoor sunlight energy. Light energy can be captured via photo sensors, photo diodes, and solar photovoltaic (PV) panels. And Electromagnetic Energy: Inductors, coils, and transformers can be considered as ambient energy sources, depending on how much energy is needed for the application.

1.2 HARVESTING METHODS

1.2.1 Piezoelectricity

Brothers Pierre and Jacques Curie discovered the piezoelectric effect in quartz crystals in 1880. In general, can be defined as the conversion of mechanical energy into electrical energy (direct effect) or conversion of electrical energy into mechanical energy (inverse effect) [8]. The direct piezoelectric effect provides that an electrical charge is generated when it subjected to a mechanical energy, whether delivered from compression, traction or just vibration. In turn, the inverse piezoelectric effect is the ability of the piezoelectric material to produce mechanical energy when subjected to an electrical charge in opposite sides [10].

1.2.2 Thermal Energy

The body temperature changes when it receives or provides energy. In this situation, the molecules are in constant motion, and this agitation is measured by temperature. Only by temperature difference can energy extraction from a thermal reservoir (e.g. body) be guaranteed. The possibility of conversion between heat

and work has been restricted to thermal machines. The Second Principle of Thermodynamics, developed by Sadi Carnot in 1824, is stated as follows [9]: "To be continuous conversion of heat into work, a system must perform cycles between hot and cold sources continuously. In each cycle, is extracted a certain amount of heat from the hot source (useful energy), which is partially converted into work, being the remainder rejected to the cold source (energy dissipated)". Carnot's equation, based on the 1st and 2nd law of thermodynamics, is a reference mathematical expression for the conversion of thermal energy into work. Its theoretical maximum efficiency in a steam engine is related to the thermal reservoirs kept at hot,  $T_h$ , and cold,  $T_c$ , temperatures [22]. The thermoelectric conversion works by absorbing and releasing heat in the connection interface between different electrical conductors (thermocouples or thermos junctions). A thermocouple is defined as a transducer composed by two metals or alloys, electrically joined at its ends, resulting in two junctions. When these joints are subjected to different temperatures, the thermocouple circuit has an electrical current. One of these joints is called the measurement junction and is subjected to temperature to be measured, while the other junction, reference junction, is applied to a known temperature, usually the temperature of an ice bath [10]. The electromotive force, which generates electric current, is generated by the difference between the joints temperatures. To measure this thermal electromotive force, the thermocouple circuit is opened at some point, where a voltmeter is introduced. After the discovery of Thermoelectricity by Alexandre Volta (1800), other studies have been developed on the effects of thermal electricity generation, which stand to Thomas Seebeck (1821), Jean Peltier (1834) and William Thomson – Lord Kelvin (1848-1854). These scientists have led to names of the three basic effects of thermoelectricity thermometry, which although different, are related among them. These effects are known as thermoelectric effects, getting these names because involve either temperature or electricity. The Seebeck effect transforms thermal energy into electricity, while the Peltier effect is related with the absorption or emission of heat in presence of an electric current in the junctions. However, both effects act in different materials. Finally, the Thomson effect presents similarities to the Peltier effect as electrical current produces a different heating effect, according to the direction of hot/cold source, but in the same material [10].

Table 1: Comparison of Vibration energy harvesting techniques [6]

	Electrostatic	Electromagnetic	Piezoelectric
Complexity of process flow	Low	Very High	High
Energy density	4 mJ cm <sup>-3</sup>	24.8 mJ cm <sup>-3</sup>	35.4 mJ cm <sup>-3</sup>
Current size	Integrated	Macro	Macro
Problems	Very high voltage and need of adding charge source	Very low output voltages	Low output voltages

1.2.3 Electromagnetic

An electric field always produces a magnetic field and, conversely, a time variable magnetic field always produces an electric field. The induction law of Faraday describes the modification that a magnetic field will induce in an electric current. In turn, the equation of Ampere-Maxwell states the modification generated by

an electric field into a magnetic field. There are already several types of electrical generators that use mechanical vibrations, including those who are present in watch and radio frequency circuits [8]. These are able to use the energy recovered and generated from the natural environment. There are two types of mechanical generators: those who use the relative motion of objects in which the generation system is connected and those that use rigid body motion. Its basic settings or construction are shown in Figure. 1.

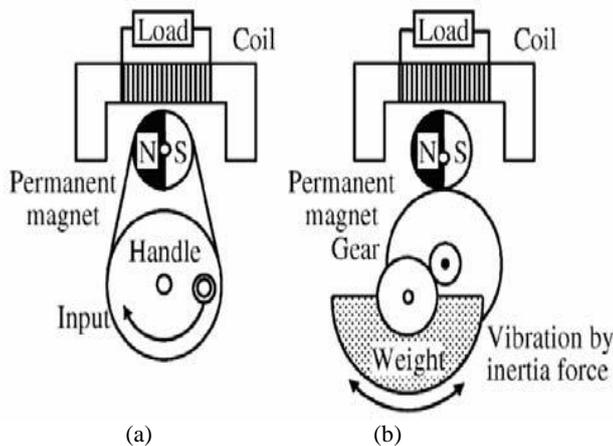


Figure 1. Types of mechanical generators: a) relative Movement b) rigid body [8]

Both systems use the electromagnetic induction principle to convert movement into electric power. The relative motion of the armature corresponding to the permanent magnet is given by the object relative motion in which the generating system is fixed. In the case of rigid body motion, the inertia force of the weight is installed on the generator. These relative movement systems are employed on bicycles' generators, radios and mobile phones. When the handle is moved 10 cm (diameter) by a force of 10 N at a rate of 3 rev/sec is produced 9.3 W (neglecting losses), 10 times higher than the power produced by the rigid body [8]. The rigid body motion type is more susceptible to vibratory movements than to constant movements, since it uses inertia, i.e. the resistance to movement. The power available for each vibration cycle is just the kinetic energy that remains in the system. Assuming that the equipment is attached to the body of a person and considering that the weight movement is equivalent to the human body motion, the kinetic energy is about 10  $\mu$ J and the electric power generated is about 10  $\mu$ W, which are lower values than those produced by relative motion. Thus, this generator can operate unconsciously and can be installed anywhere, obtaining a considerable amount of energy. There are some effective methods for this mechanism, as resonance generators, self-excitation generators and rotational generators as gyroscopes [8].

### 1.3 Direct and Inverse Piezoelectric Effect

The Pressure applied generates charges on the surface of piezoelectric materials. This direct piezoelectric effect, also called generator or sensor effect, converts mechanical energy into electrical energy. Vice versa, the inverse piezoelectric effect causes a change in length in this type of materials when an electrical voltage is applied. This actuator effect generated converts electrical energy into mechanical energy. The piezoelectric effect occurs both in monocrystalline materials and in polycrystalline ferroelectric

ceramics. In single crystals, an asymmetry in the structure of the unit cells of the crystal lattice, i.e. a polar axis that forms below the Curie temperature  $T_C$ , is a sufficient prerequisite for the effect to occur. Piezoelectric ceramics additionally have a spontaneous polarization, i.e. the positive and negative charge concentration of the unit cells is separate from each other. At the same time, the axis of the unit cell extends in the direction of the spontaneous polarization and a spontaneous strain occurs [3].

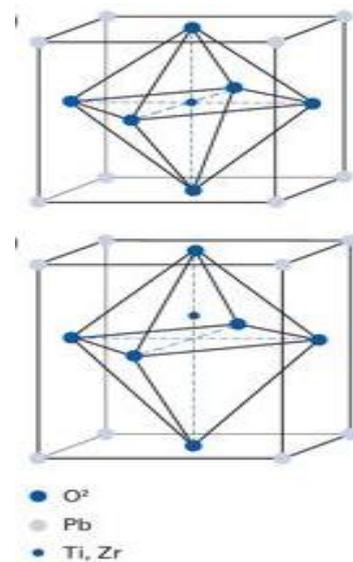


Figure 2. Direct and indirect piezoelectric effect [3]

### 1.4 Types of Piezo materials

#### 1.4.1 Soft Piezoelectric Materials

Ideal for piezo actuators and sensors. Ferroelectrically soft piezo ceramic materials can be polarized fairly easily even at relatively low field strengths. This is due to the comparably high domain mobility typical for them. The advantages of soft PZT materials are their large piezoelectric charge coefficient, moderate permittivities and high coupling factors [4].



Figure 3. Soft Piezoelectric materials

### 1.4.2 Hard Piezoelectric Materials

The materials are High Performance Material mostly used for Ultrasonic Transducers. Ferroelectrically hard PZT materials can be subjected to high electrical and mechanical stresses. Their properties hardly change under these conditions. The advantages of these materials are their moderate permittivity, large piezoelectric coupling factors, high mechanical qualities and very good stability under high mechanical loads and operating field strengths. Low dielectric losses facilitate their continuous use in resonance mode with only low intrinsic heating of the component [4].



Figure 4. Hard Piezoelectric materials

Table 2: Summary of Several Piezoelectric Materials [2]

Summary Of Several Piezoelectric Materials Investigated.			
Author	Type Of Material	Advantages/Disadvantages	Power Harvesting Capabilities
Lee <i>et al</i> (2005)	Monolithic PZT	Most common type of device. Not flexible. Susceptible to fatigue crack growth during cyclic loading	N/A
Lee <i>et al</i> (2004, 2005)	PVDF film coated with PEDOT/PSS electrodes	Resistance to fatigue crack damage to electrodes	N/A
Mohammadi <i>et al</i> (2003)	Piezofiber composite	Increased flexibility	120 mW from 34 × 11mm plate of 5.85 mm thickness
Churchill <i>et al</i> (2003)	Piezofiber composite	Increased flexibility	7.5 mW from 130 × 13 mm patch of 0.38 mm thickness
Sodano <i>et al</i> (2004a)	MFC composite quick pack IDE quick pack	MFC—flexibility, MFC and quick pack IDE—low-capacitance devices quick pack—energy harvesting capability	Quick pack proved to harvest the most energy

### 1.5 INDUSTRIAL APPLICATIONS

In the 80's, Seiko developed a kinetic watch powered by human movement. It dispensed the conventional batteries, being the human arm movement used instead. Since then, several kinetic watches were developed, but the potential of this system to power larger devices is limited by the slowness how people move and consequently reduced arm movement. According to [11], the American and British armies have tried to power up sensors placed in soldiers' boots. These devices allow radiotelephone operation, which is often equipped with heavy batteries. However, the energy harvesting devices were not sufficiently robust to withstand extreme conditions [12]. In the early 90's, Freeplay marketed devices such as radios, lamps and lanterns with handles to provide increased capacity of energy availability through the incorporation of this type of energy harvesting systems. Since then it has developed generators with cranks to charge mobile phones, foot pumps capable of powering larger appliances and a series of prototypes of medical equipment with handles. The introduction of piezoelectric materials, as Polyvinylidene fluoride (PVDF), in shoes in order to recover some power from walking offers several advantages. Note that a piezoelectric plate is only 1.1 mm thick (without electrodes), having a reduced weight and high duration, thus promoting the flections needed for power generation by the natural deformation of the shoe during walking [13]. In order to regain power by the force exerted on the heel and toes, [14] integrated Piezo elements in the shoe's removable sole. Figure 5 shows this type of material and how it is designed to be placed in a shoe. Due to the limited efficiency of the electromechanical conversion, the average power produced is respectively 8.3 mW on heel and 1.3 mW on toes during a walk.

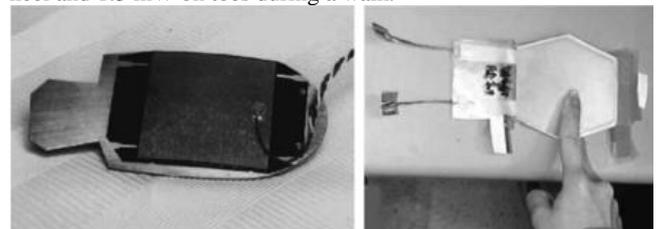


Figure 5. Piezoelectric application [14]

In order to improve these results, [15] applied an elastomer generator in the heel of a boot, as shown in Figure 6.

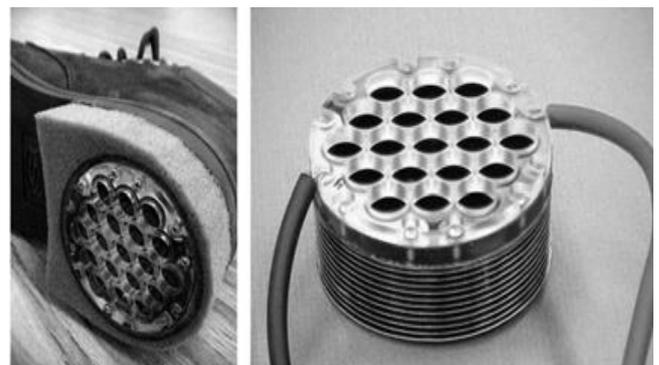


Figure 6. Electrostatic generator based in the compression of a dielectric elastomer [15]

When the heel is pressed against the ground, the pad compresses the implemented elastomeric membrane producing a voltage. When a voltage is applied across the electrodes, it produces energy. Another application that uses the walk movement to generate energy considers the insertion of the piezoelectric materials in the floor. In this case, the floor beneath our feet acquires, accumulates

and converts into electricity the energy generated by the passage of people, rather than applying it to the shoe [16]. According to studies conducted by [17], each step produces 8 W. This power is absorbed by the floor, being possible to capture at least 30% of that energy. In this context, it is possible to imagine a dance floor where the floor is designed to reduce vibration and disperse energy, capturing it and generating electricity, as it is equipped with energy scavengers under the surface. Considering the natural walk movement, [18] tried to implement magnetic generators in shoes, as shown in Figure 7. This prototype is implemented in a shoe only with the following components i.e. a spring, a pendulum and a generator system that produces a peak power near 1 W, i.e. the produced enough energy to power a radio while walking. However, these generators are difficult to integrate in shoe, without causing discomfort to the user after wearing the shoes, since the mechanical system has proved quite intrusive.



Figure 7. Rotating generator adapted in a shoe [18]

Thus, [19] developed a model to improve the integration of the generator in the shoe's sole, as shown in Figure 8. As the rotating generators need to turn quickly to achieve the desired efficiency, all other systems that involve significant gear relationships, make a considerable mechanical complexity and a reasonably high torque, leading to a high probability of collapse [8].

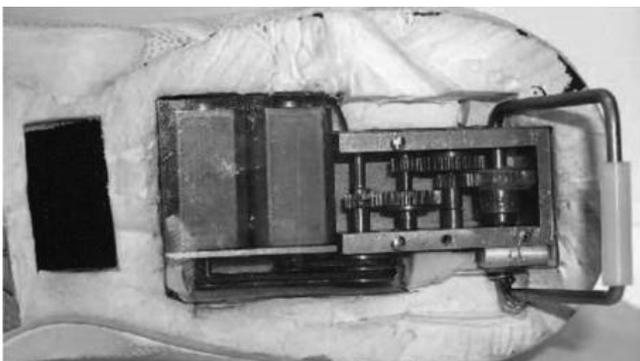


Figure 8. Improvement of the rotational generator, with two magnetic generators built in the shoe's sole [19]

Since the electromagnetic systems can be made of a coil and a permanent magnet attached to a spring, this mechanical movement caused by structural vibration, induces a voltage at the coil's terminal that converts it into an electric charge. The magnetic field in the coil will be easily induced if the magnet is large. However, the size and layout of the magnet is limited by the spring and the structure of the device itself [8].

#### 1.5.1 Asphalt solar collector combined with piping system

Energy harvesting from surfaces that serve as solar collectors is no longer conceived as a new technology and is often discussed in combination with embedding pipes and pumps in particular arrangements to harvest the extracted solar energy and convert it to

thermal or electric energy. These so called 'asphalt collectors' are also known as asphalt solar collector (ASC) and they circulate water through a series of pipes below the pavement surface for use. The principle for the technique is that the radiation from the sun and atmosphere is absorbed in the pavement through an increase in warmth which is captured by water piping system and stored in the ground or other storage reservoirs over summertime. The stored energy could then be used for supporting nearby facilities for district heating and cooling, electricity, recharging or de-icing the roads (e.g. via a hydronic system).

#### 1.5.2 Photovoltaic (PV) applications in the road infra

Researchers at one of the Korea Institute also investigated several approaches to harvest solar energy from asphalt pavements. In addition to the heat generated inside the pavement itself, they also intended to identify if it is feasible to utilize current solar cell or photovoltaic technologies by embedding those into the pavement infrastructure. It should be noted, however, that current thin film solar cells are difficult to use in surfaces that receive vast mechanical load cycles and environmental conditioning could cause premature corrosion and wear. For this reason the researchers are developing new thin film solar cells that can meet the requirements for using it on road surfaces.

### IV. PROPOSED SYSTEM

This paper proposes the idea of a system for passing or supplying electricity to tunnels by producing and harvesting the electrical energy, storing that energy in capacitor and supplying energy to tunnels only when the train arrives at the tunnel. Piezo cells will be placed underneath the tracks. The energy produced from the pressure will be passed on to capacitor for storage. Using sensors the arrival of train at the tunnels will be sensed and electricity will be supplied to Led's i.e. tunnels.

### V. SYSTEM DESCRIPTION

#### 1.6 Piezoelectric Effect

The piezoelectric effect describes the relation between a mechanical stress or pressure and an electrical voltage in solids materials. It is reversible: an applied mechanical stress will generate a voltage and an applied voltage will change the shape of the solid by a small amount (up to a 4% change in volume) [1].

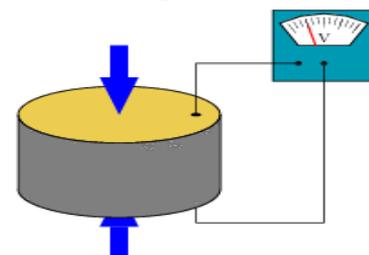


Figure 9. Piezoelectric Effect [1]

Piezoelectric ceramics have been used for many years to convert mechanical energy or pressure into electrical energy. The following sections describe the range of piezoelectric generators described in the literature to date. For the purpose of this review, piezoelectric generators have been classified by methods of operation and applications and include both macro scale (>cm) and micro scale ( $\mu\text{m}$  to mm) devices. It begins with a brief description of piezoelectric theory in order to appreciate the different types of generator and the relevant piezoelectric material properties [1].

#### 1.7 Infrared Proximity Sensor

A proximity sensor is a sensor able to detect the presence of nearby objects without any physical contact. A proximity sensor often emits an electromagnetic field or a beam of electromagnetic

radiation (infrared, for instance), and looks for changes in the field or return signal. The object being sensed is often referred to as the proximity sensor's target. Different proximity sensor targets demand different sensors. For example, a capacitive or photoelectric sensor might be suitable for a plastic target; an inductive proximity sensor always requires a metal target. The maximum distance that this sensor can detect is defined "nominal range". Some sensors have adjustments of the nominal range or means to report a graduated detection distance. Proximity sensors can have a high reliability and long functional life because of the absence of mechanical parts and lack of physical contact between sensor and the sensed object [21]. This infrared sensor will be used in this system for detection of arrival of the train at tunnel point. This sensor will be placed at the tunnel end and not at the tunnel starting point considering the direction of running train. Distance for the arrival of train will be managed in the sensor as per the requirement.



Figure 10. Infrared Proximity Sensor [23]

## VI. IMPLEMENTATION DETAILS

The aim of the system discussed in this paper is to generate electrical energy from applied mechanical force or any physical force and then converting that force into electrical energy, which further can be stored and can be used for various electrical purposes. The Piezo cells will first be implemented under the track of toy train where the track of the toy train or entire system will be demonstrated on a wooden ply. The piezo cells will be connected to the capacitor via connecting wires; also a rechargeable battery will be connected to the piezo cells. LEDs will be placed beside the tracks which will be connected to the capacitor through a wire. As soon as the train starts working i.e. starts running on the track, pressure will be produced on the tracks; where the piezo cells under the track will be pressed due to the pressure of the train on it, the piezo cells will convert this pressure or force into electrical energy form which will be then supplied to the capacitor to store the electrical energy produced from the pressure of the running train. The electrical energy stored in the capacitor will be the supplied at appropriate voltages to the led's which will act as lights inside the tunnels. The stored electrical energy will only be supplied to the led's or tunnels only when the train arrives at the tunnel point. The arrival of the train at the tunnel point can be detected using sensors which will sense the sensory information or the arrival of the train and will allow the capacitor to supply the appropriate amount of electrical energy to the tunnels or the led's. Once the train is out of the tunnel the power supply will be cut and the led's will shut down or lights will be off. Thus using this technique energy harvesting can be successfully done without harming or polluting environment as compared to other energy harvesting methods.

## 1.8 Modules

The overall modules of the system are two modules. Following are the listed and described below:

### 1.8.1 Conversion of pressure to electrical energy

This module is design for the conversion of mechanical force/energy or pressure to electrical energy. The pressure generated by train on tracks is taken onto Piezo crystals which are placed under the tracks. These Piezo crystals then convert the mechanical energy to electrical energy. This electrical energy is then stored in the capacitor for its further use when needed.

### 1.8.2 Sensing the arrival of train at tunnel point

This module is design for sensing the arrival of train at the tunnel point so that if the train is going to arrive at the tunnel then the capacitor which is storing the electrical energy will supply the electricity for the tunnel lights i.e. LED's.

## VII. DESIGN OVERVIEW

### 1.9 Block diagram

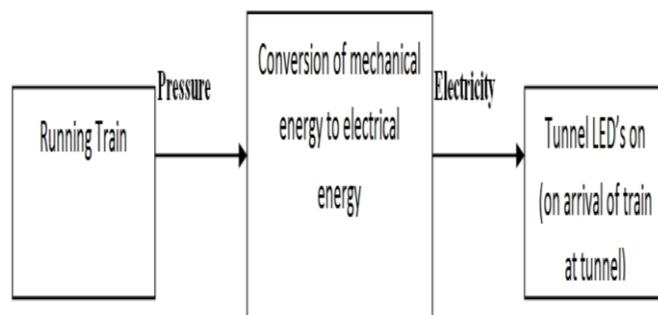


Figure 11. Block diagram of the system

### 1.10 System Architecture

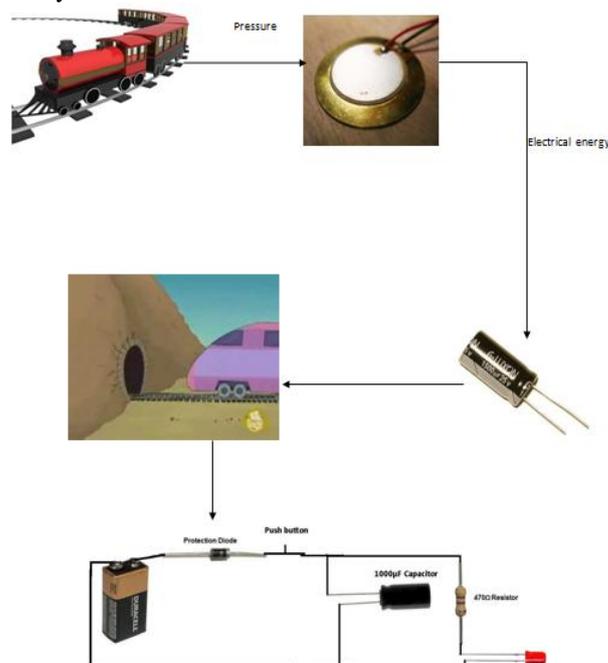


Figure 12. System architecture

1.11 Flowchart

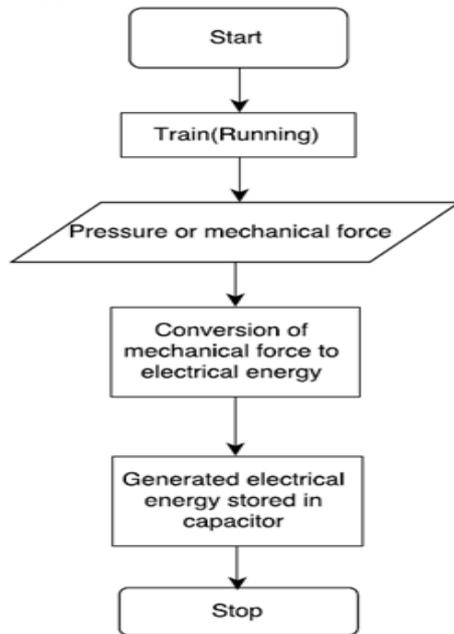


Figure 13. Conversion of pressure into electricity

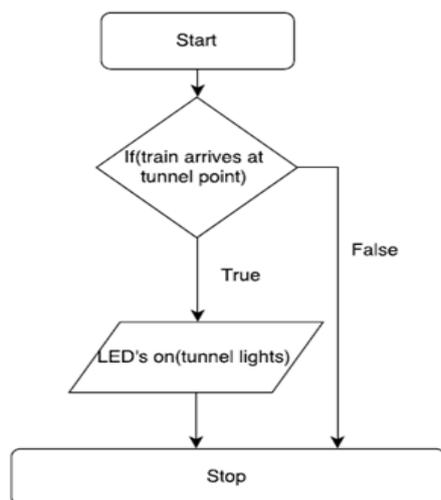


Figure 14. Sensing arrival of train

VIII. FUTURE WORK

Thus the proposed idea discussed in this paper would be further implemented in future considering all the above methodologies.

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