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RESEARCH ARTICLE

HARVEST MOBILE ROBOT DRIVEN BY A TRIBOELECTRIC NANOGENERATOR WITH PIEZOELECTRIC STARTUP.

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Abstract

Energy is the essential requirement of today's life. Due to the diminution of the energy sources, we need to develop the device which can harvest the wasted energy existing in our ambient environment. Triboelectric nanogenerator (TENG) was developed as an innovative paradigm for energy harvesting, which can harvest various forms of mechanical energy that exist in our day to day life, including vibrations, walking, ocean waves, human motions, raindrops, flowing water, a moving automobile, wind, rotation energy and mechanical triggering. Triboelectric nanogenerator (TENG) is a novel energy harvesting device to convert mechanical energy into electricity based on triboelectric principle. This paper reports triboelectricnanogenerator for efficiently harvesting electrical energy from the rotational motion of the robot's wheel, also paper works on designing robot's circuit does not need any external reference battery using a piezoelectric startup circuit. However, as the availability of harvest energy source is intermittent, there is a need to devise a backup power system so as to be able to store the electricity produced by nanogenerator and thereby have a readily available source of energy at all times. This paper analyzes and presents a concise review of renewable & harvesting energy technology, especially in robotics, and learn more about how to incorporate the right mobile robot power source, and seeks to demonstrate that renewable energy storage solution can be attached and stored.

Introduction:-

The robotic technology already plays a vital role in modern life, and its influence is set to grow exponentially over the coming decades in order to modernize global production procedures and remote environmental sensing techniques. The lack of compact, efficient, and lightweight power sources impedes the realization of mobile robotic devices that operate autonomously for periods of hours, while the technology for mobile robotic platforms, communication, information processing, and automation has accelerated, similar breakthroughs for power sources have not kept pace. With the estimated population of mobile robots and the resulting demand for massive energy consumption, make the power source powering a mobile robot is a critical decision, affecting the mobile robotic process and output. Generally, batteries have been the source of energy for most mobile, embedded and remote system applications. But in the modern, Renewable and harvest energy can provide the solution as a viable alternative energy source to meet the special energy demands that are typically required to operate embedded

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systems and robots. Various alternate sources of energy have been explored for obtaining a sustainable form of energy to power various autonomous wireless & portable devices. Renewable & harvesting energy technology solutions will be required and engineers have already come up with various alternative sources of energy power systems into robots.

The paper is organized as follows: Section 2 gives a brief overview of the energy sources for a robot. Section 3 gives a brief discussion of energy harvesting systems Section 4 presents the proposed system and suggestions for future research efforts necessary for the improvement of energy generators. Section 5 concludes the paper.

Power Solutions For Mobile Robot:-

The selection of a mobile robotic power source should be the decision made in the early stages of the design since it impacts the complete system because mobile robots are expected to work tireless hours, yielding perfect, precise results around the clock. Power system alternatives include batteries, fuel cells and generators, thermo-electric generators, super capacitors, flywheels and even non-storage options. A useful power technology should be self-contained and not depend on external components or energy. For this reason and others, solar power does not appear to be an option due to the long recharge time for battery systems, depending on environmental conditions and the relatively large cross-sectional area required for appreciable power generation.

Batteries:-

There are many variations on a theme, but the primary battery technologies for commercial class mobile robots are Lead-Acid, Nickel-Cadmium, Nickel-Metal Hydride, and Lithium- Ion. The type of battery that is used for a mobile robot varies depending on the safety, life cycle, and weight. Lead acid batteries are common, as are silver-cadmium batteries. Rechargeable batteries and primary batteries are both used, batteries that are not rechargeable are generally more powerful.

Fuel Cells:-

A fuel cell derives the energy it delivers from whatever "fuel" is provided, which is typically hydrogen. The electrical output is generated at a constant level until the fuel runs out. There are many types of fuel cells, characterized by the type of electrolyte they use, and all are relatively new choices for robot developers. Three types of fuel cells are Polymer Electrolyte Membrane, Direct Methanol, and Solid Oxide Electrolyte.

Solar Power Systems:-

The sun generates a huge amount of energy which is dissipated in Space, only a small fraction of this energy reaching earth in the form of light and other radiations. Solar energy is, in principle, pretty easy to use, it is captured directly from the sun and stored. For example, IMRP was designed to run on fuel cells using a low-pressure metal hydride hydrogen storage system which stores more energy on board than a rechargeable battery could, and a suitable method of storing solar energy used hydrogen as a medium for storage, using metal hydride in [1].

Renewable energy:-

Renewable energy can provide a viable alternative energy source to meet the special energy demands that are typically required to operate mobile robots. Renewable cells are well known for their use as power sources for satellite, environmentalist green energy campaigns, and pocket calculators. Commonly these consist of a renewable cell which charges a capacitor and a small circuit which allows the capacitor to be charged up to a set voltage level and then be discharged through the motor(s) making it move, for instance [2], which invented a system for resupplying power to self-contained mobile equipment, including a fixed station having an external power source and consisting of a high-frequency generator and an induction coil as well as, on or in the equipment, a pick-up coil, a current filtering and rectifying device, a rechargeable battery pack, and a microcomputer-controlled tracking system. The microcomputer is connected to the drive control system of the equipment and applies a drive algorithm to the fixed station when the battery charge level drops below a predetermined level; the algorithm is based on a measurement of higher-frequency generator signal reception strength gradient.

Ambient energy harvesting technology:-

Energy harvesting is a future energy supply for filling the gap between the energy supply and demand of reliable, clean and low-cost energy, which originated from the windmill and water wheel, is widely being considered as a low maintenance solution for a wide variety of applications. The energy harvesting sources can be used to increase the lifetime and capability of the devices by either replacing or augmenting the battery usage. The devices powered by energy harvesters can be used to provide vital information on operational and structural circumstances by placing them in inaccessible locations.

The Sources Of Harvest Energy:-

The process of extracting energy from the surrounding environment is termed as harvesting energy. A number of sources of harvestable ambient energy exist, including thermal energy, sound energy, radio frequency, light, mechanical energy & wind energy. Energy scavenging devices are designed to capture the ambient energy surrounding the electronics & convert it into usable electrical energy. An alternative source of energy is required in the fields of embedded systems, wireless sensor networks and low power electronics such as MEMS devices. Also with the limited capacity of finite power sources and the need for supplying energy for a lifetime of a system, there is a requirement for self-powered devices [3]. There are many sources of energy available for harvesting like:

Thermal energy:

Thermal energy can be obtained from the heat present in the ambiance or from heat generated during some process. Either thermo-electric or pyroelectric effects can be used to harvest energy [4].

Mechanical energy:

Vibrations in some situations can be very large, like in case of the vibrations of civil structures like tall buildings, railroads, ocean waves, & even human motions & can give a better output power.

Sound energy:

The sound energy is almost present continuously & at a considerable level in the environment for e.g. On the railway track, runway, shipyard, or on the road (engine noise of vehicles & horns), loud music played in clubs or parties, at construction sites & other such sources etc. [5].

Wind energy:

This wind flow, or motion energy, when harvested using huge wind turbines, can be used to generate electricity on a large scale [6].

Radio frequency:

Radiofrequency (RF) is any of the electromagnetic wave frequencies that lie in the range extending from around 3 kHz to 300 GHz [7].

Light:

Light is electromagnetic radiation within a certain portion of the electromagnetic spectrum. Visible light is usually defined as having wavelengths in the range of 400–700 nanometers (NM), between the infrared (with longer wavelengths) & the ultraviolet (with shorter wavelengths). This wavelength means a frequency range of roughly 430– 750 terahertz (THz).

Solar cells are the most mature and commercially established energy-harvesting solution [8] and of course, it exploited across a wide range of size scales and power levels. While cost is a key parameter for a large-scale photovoltaic generation, at the small scale of portable electronic devices this is less of an issue, and light availability is instead the key limitation. Energy harvesting approaches that transform light, heat and kinetic energy available into electrical energy offer the potential of renewable power sources which can be used to directly replace or augment the battery. Such renewable sources could increase the lifetime and capability of the system and mitigate the environmental impact caused by the disposal of batteries. [9] Designed a silicon vibration-powered generator. A small electromagnetic generator utilizing discrete components and optimized for a low ambient vibration level based upon real application data was presented in [10]. The generator delivered 30% of the power supplied from the environment to useful electrical power in the load. The design of miniature generators capable of converting ambient vibration energy into electrical energy for use in powering intelligent sensor systems as described in [11]. A device had been described which can produce an average power of 157 µ_W when mounted on the engine block of a car. Piezoelectric Nanogenerators open new avenues for ambient power harvesting through foldable power options and miniaturization of power packages, so [12] used vibration energy harvesting by using piezoelectric generators for wireless sensor devices. A system in [13] viewed motion driven miniature energy harvesters for suitable applications, converted ambient mechanical vibration into electrical energy for powering autonomous low power electronic systems. A complete energy harvesting power supply for implantable pacemakers had been proposed in

[14]. The designed power supply included an internal startup and did not need any external reference voltage, which TEG provided the input voltage for the circuit from the temperature difference found between the body and the ambiance. High output performance with various rotation speeds and magnetic force was achieved in [15], which a seesaw-structured triboelectricnanogenerator (S-TENG) for efficiently harvesting electrical energy from the rotational motion of mechanical systems was proposed to drive small electronics and the wireless sensor node. [16] designed a self-powered electrospinning system, which was composed of a rotating disk TENG (R-TENG), a voltage-doubling rectifying circuit (VDRC), and a simple spinneret, which generated an alternating voltage up to 1400 V, and by using a voltage-doubling rectifying circuit, a maximum constant direct voltage of 8.0 KV can be obtained under the optimal configuration and was able to power the electrospinning system for fabricating various polymer nanofibers.

Storage Solutions:-
Ambient light, thermal gradients, vibration/motion, or electromagnetic radiation can be harvested to power electronic devices. At the same time, all energy-harvesting-based systems need energy storage for times when the energy cannot be harvested (e.g., at night for solar-powered systems). Rechargeable batteries known as “secondary” cells to differentiate them from “primary” or single-use cells are usually specified for this task. Depending upon the energy harvester, the load demands, and various other system design considerations, there are many options for a storage battery solution. High discharge rates, low self-discharge, high energy density, and other performance characteristics are vastly different among the secondary cell chemistries currently available. Energy storage is a key element of the energy harvesting system because it is a bridge of stability between the energy source and the load that provides a constant energy flow from an otherwise variable environmental source. The power interface circuit condition the harvested energy to enable the charging of low capacitor batteries or supercapacitors and also provides compatibility with the load requirements. "Storage has the effect of making renewable energy even more valuable because you can schedule it. You can control and dispatch it when you want it," says Janice Lin, who leads the California Energy Storage Alliance and the newly founded Global Energy Storage Alliance [17]. In general, energy can be stored in a capacitor, super capacitor, or battery. Capacitors are used when the application needs to provide huge energy spikes. Batteries leak less energy and are therefore used when the device needs to provide a steady flow of energy. To help understand the diverse approaches currently being deployed around the world, we have divided them into six main categories:

A. **Solid State Batteries:** a range of electrochemical storage solutions, including advanced chemistry batteries and capacitors
B. **Flow Batteries:** batteries where the energy is stored directly in the electrolyte solution for longer cycle life, and quick response times
C. **Flywheels:** mechanical devices that harness rotational energy to deliver instantaneous electricity
D. **Compressed Air Energy Storage:** utilizing compressed air to create a potent energy reserve
E. **Thermal:** capturing heat and cold to create energy on demand
F. **Pumped Hydro-Power:** creating large-scale reservoirs of energy with water.

The Proposed Scheme "Analysis &Design "

Line Follower Arduino Robot:-
Line follower is an autonomous robot which follows either black line in white area or white line in the black area. The robot must be able to detect particular line and keep following it. Line following is a task in which robot has to follow the line. It must be capable of taking various degrees of turns to follow the curved lines also. The line sensors are used to sense the line when the signal falls on the white surface, it gets reflected, and if it falls on the black surface, it does not reflect this principle is used to scan the Lines for the Robot. The Robot should be capable of taking various degrees of turns and must be insensitive to environmental factors such as lighting and noise. The robot will be using two IR sensor pair which will have an IR LED and Photodiode. Generally, IR rays will be reflected by the white surface while a black surface will absorb IR rays. In the line follower that builds, both the IR sensors will be on the white surface. IR rays will be emitted and reflected back which will be detected by the Photodiode, in this state the IR sensor will send a HIGH digital signal ("1"). Similarly, when the sensor is on a black surface IR rays will be emitted and will not be reflected back which will be absorbed by the black surface, in this state the IR sensor will send a LOW digital signal ("0"). Thus, with these digital values 1 and 0, we can easily identify the state of the sensors. A line follower mechanism for the Arduino Robot can be shown as below:

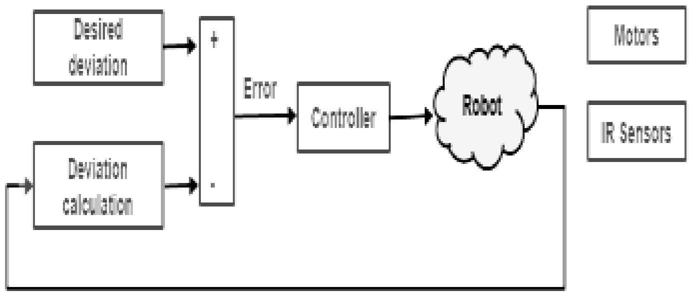

Fig. 1: - A line follower mechanism for the Arduino

Required Hardware:

Design Line Follower Arduino Robot needs IC7805 Voltage Regulator, L293D Motor Driver, IR LED pair, two 300-500rpm DC Motors, Piezoelectric (initial power supply), Chasis, Castor wheel, Wheels. Sensor section contains IR diodes, potentiometer, Comparator (Op-Amp) and LED. The potentiometer is used for setting reference voltage at comparator's one terminal and IR sensors are used to sense the line and provide a change in voltage at the comparator's second terminal. Then comparator compares both voltages and generates a digital signal at the output. Here this ***line follower circuit*** *uses two comparators and two sensors. LM 358 is used as a comparator. LM358 has inbuilt two low noise Op-amps. Arduino Pro Mini* ***used in the control section*** *for controlling whole the process of line follower robot. The outputs of comparators are connected to digit pin number 2 and 3 of the Arduino. Arduino reads these signals and send commands to the driver circuit to drive line follower, and driver section consists of the motor driver and two DC motors. The motor driver is used for driving motors because Arduino does not supply enough voltage and current to the motor. So a motor driver circuit to get enough voltage and current to the motor is added. Arduino sends commands to this motor driver and then it drives motors. The robot uses two IR sensor modules, namely left sensor, and right sensor, and two 500rpm DC motors. These motors work when they are connected to any DC power source and the direction of rotation of the motor can be changed by changing the polarity of the source. IC L293D is used to control the motors which work with digital I/O. Assume that the input given to the motor through* ***L293D*** *is HIGH ("1") and LOW ("0") that make the motors to rotate in a clockwise direction, similarly when the inputs are LOW ("0") and HIGH ("1") the motor rotates in an anticlockwise direction. But when both the inputs are same (1 & 1 or 0 & 0) the motors don't work.*

When both left and the right sensor senses white, then robot move forward.

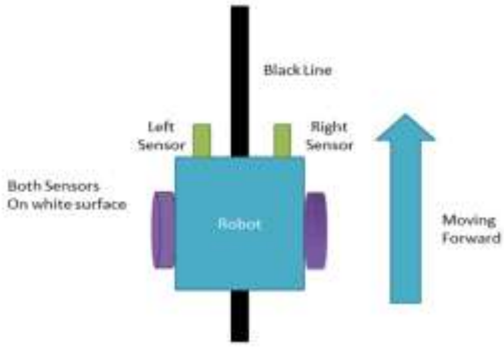

Figure (2 - a)

If the left sensor comes on black line, then robot turn left the side.

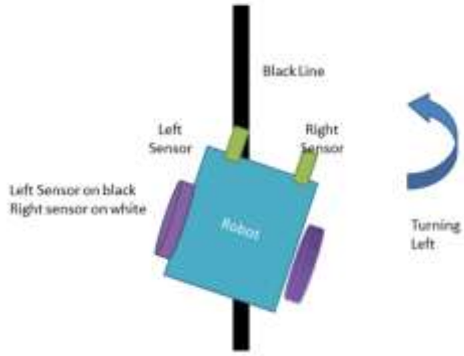

Figure (2 -b)

If the right sensor senses black line, then robot turn right side until both sensors come on the white surface. When white surface comes robot starts moving on forward again.

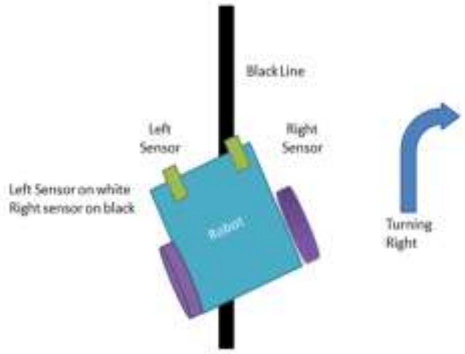

Figure (2 - c)

If both sensors come on the black line, the robot stops.

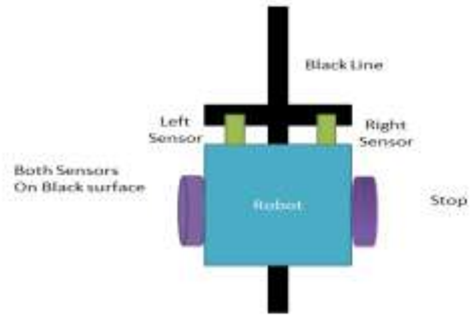

Fig (2 - d)

The digital signal given to the INPUT 1, 2, 3 and 4 of L293D will be thrown back to the OUTPUT 1, 2, 3 and 4 respectively. The INPUT 2 and 3 of L293D is connected to ground, which is LOW ("0") and the signal from the IR sensors are connected to INPUT 1 and 4. Hence the value of OUTPUT 2 and 3 will be constantly LOW ("0") while the value of OUTPUT 1 and 4 will be HIGH ("1") when the IR sensor is on the white surface and will be LOW ("0") when the sensor is on black surface.

Circuit diagram of robot

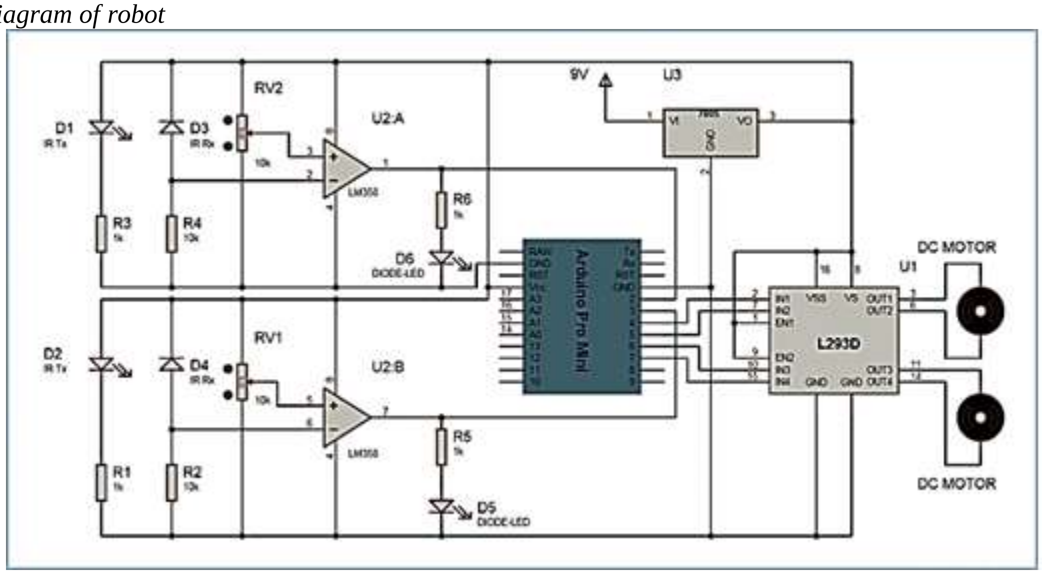

Fig. 3: - Circuit diagram of robot

Robots, like any devices to function, need a source of power in order to work, which could be built with a gasoline-powered engine and pneumatic actuators. But for the most electronic components are powered by electricity, usually by batteries. This is the most common and practical way to power most robots, especially mobile robots. In fact, most mobile robots on the market today are powered by renewable energy.

Proposed power system

This Paper moves to design the electrical power system of a robot, which consists of two power systems. The first system is Self-Powered Startup using Piezoelectric, and the second system is the energy harvester using integrated triboelectricnanogenerator. In this paper, the combination of piezoelectric generator and energy harvesting condition circuit are used to verify the functionality of self-power robotics.

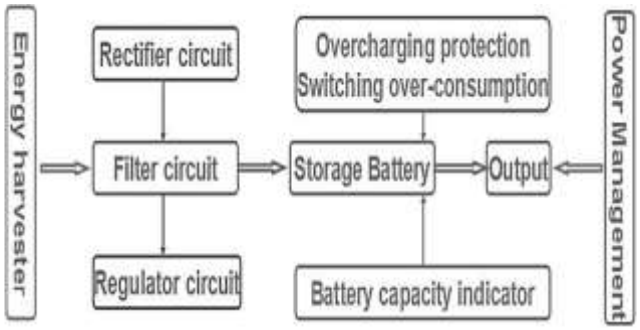

Fig. 4: - Piezoelectric Energy harvest system

Self-Powered Startup using Piezoelectric

The battery is usually the raw power source for a robot, but the full electrical powering system consists of also a regulating circuit to stabilize and process the source, and a switch to turn on or off the power. The self-powered system is remarkably attractive for building a sustainable and environmental concern application to replay batteries. The piezoelectric effect is the conversion of applied mechanical force of internal electrical energy. The inverse (aka reverse or transverse) piezoelectric effect converts applied electrical energy into the internal mechanical strain.

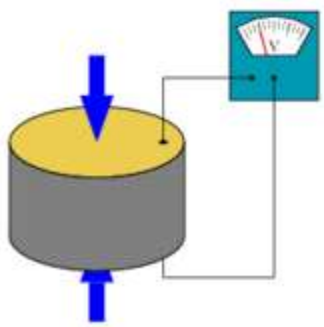

Fig. 5: -A piezoelectric disk generates a voltage when deformed

a) Component Details:
1) Rectifier (MIC DB 107)
2) DIA-Electric Capacitor (1, 10, 22, 47, 100, 150uf).
3) SPDT Switch
4) Piezo –Plate.
5) Jumper wire.
b) *Piezoelectric Circuit Diagram:*

The below is the schematic diagram of the **Piezoelectric Circuit, where** the energy stored in the capacitor will be dissipated only when the tactile switch is closed.

The energy stored in a capacitor is given by the equation:

$$E = \frac{1}{2}V^2C \quad (1)$$

For our circuit, C = 220 µF. When the multimeter shows 10 volts across the capacitor, the amount of energy stored is

$$E = \frac{1}{2}(10\,V)^2(220\,\mu F) = \mathbf{0.011\ joules} \quad (2)$$

If a single tap on the piezoelectric element increases the voltage from 2 V to 2.05 V, the amount of energy generated for each tap is

$$E = \frac{1}{2}(2.05^2 - 2^2)(220\,\mu F) = \mathbf{0.000022\ joules/tap} \quad (3)$$

By using multimeter begins with addressing the power output as a function of vibration frequency.

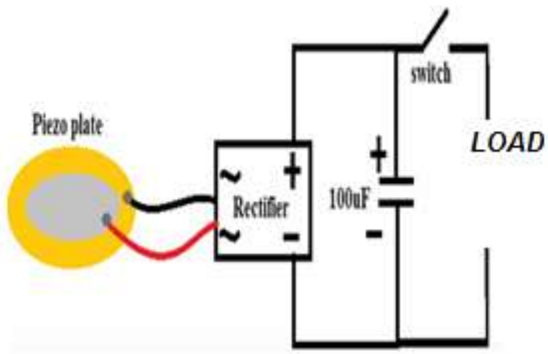

Fig.6: - Piezoelectric element generation circuit.

2) Tir integrated triboelectricnanogenerator energy harvesting system for powering robot

This paper provides a theoretical simulation method for integrated triboelectricnanogenerator systems through integrating the equivalent circuit model of triboelectricnanogenerators into the SPICE software. Paper represents integrated triboelectricnanogenerator energy harvesting systems that contain triboelectricnanogenerators, power management circuits, energy storage elements. A Wheel includes a rim and a tire. The rim, includes a ring body defining a central axis, two finagles, and 6-TENG into two rings. When the vehicle moves and the wheel roll, pressure generated by the ground will be applied to the 6-TENG rings. Then, the TENG rings transform the mechanical energy to electric energy. Energy reuse can be achieved and additional energy consumption can be avoided, where the TENG rings to transmit the electric power to the electronic devices and/or the storage battery in the vehicle via wires. Thus, the additional electric energy is used for charging the battery and/or powering the electronic devices. The TENG rings to transmit the electric power to the storage element to be stored.

A Wheel comprising

A ring body defining a central axis thereof, two flanges extending from the circumference of the ring body around the central axis, a first annular groove defined in the circumference of each flange around the central axis; two TENG rings mounted in the respective first annular grooves and configured for producing electric power under pressure; and a tire enclosing the rim.

S-TENG design and characterization:

A TENG film with a size of (1*1) cm^2 was attached to the surface of a rubber wheel (7cmindiameter) with the rough surface facing outward. The back electrode is connected to the metal rim on the wheel for inducing charge collection. The wheel is driven by a computer-controlled linear actuator with controlled linear speeds. A poly Oxy methylene plastic bar (61cminlength) is added between the actuator and wheel to avoid the electric-field noise generated by the electromagnetic actuator. The electrical outputs of the TENG are measured.

S-TENG on vehicle demonstration

TENGs (1.5_3.5cm2 each) are attached to the tire surface of a robot (each back wheel has 3-TENGs). A piece of Al foil is placed on the bottom of the tire surface as the reference electrode. The TENG can be embedded into the SPICE software as a basic element consisting of a voltage source in serial connection with a capacitor. The system simulates in SPICE.

The circuit used to store energy generated from TENG accumulated charge and stored energy in a 10µF capacitor over 5 minutes (540 cycles. The graphic diagram of a sample energy-harvesting circuit and TENG directs power to drive Line follower robot.

In real applications, first, the load circuits are usually a combination of linear and nonlinear elements, including resistors, diodes (rectifiers), transistors, capacitors, inductors (transformers), and so forth. Besides, the real mechanical motion could be quite irregular. Moreover, the triboelectricnanogenerator itself is not so ideal and cannot be analytically represented. Therefore, the simulator is used to hold these problems.

A power management circuit is very necessary to convert these AC outputs from TENGs to DC output.

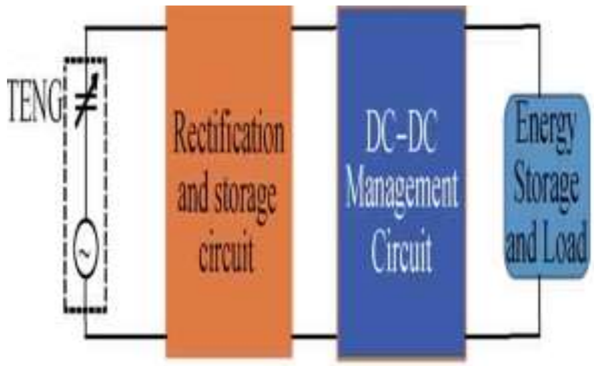

Fig. 7: - Structure of the TENG utilized with power management circuits

Analytical Model Triboelectric Energy Harvesting

The model can be modified to calculate the current, voltage, charge, and power output under different experimental conditions. This is in contrast to the few models that exist and is restricted to known simple geometries, derived using the parallel-plate capacitor model [18].

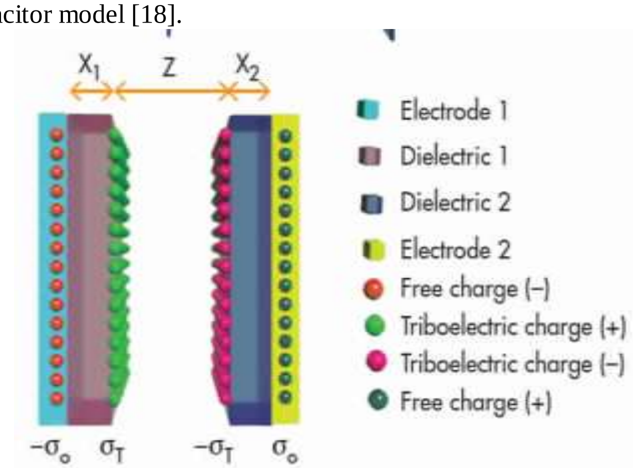

Fig.8: - The structure and the charge distribution of a typical contact-mode TENG

The figure illustrates the structure and the charge distribution of a typical contact-mode TENG. The model introduces the concept of a distance-dependent electric field derived using the finite dimensions of the charged layers (a factor not taken into account in previous models) and is applied to almost any surface or geometry (Fig. 8.).

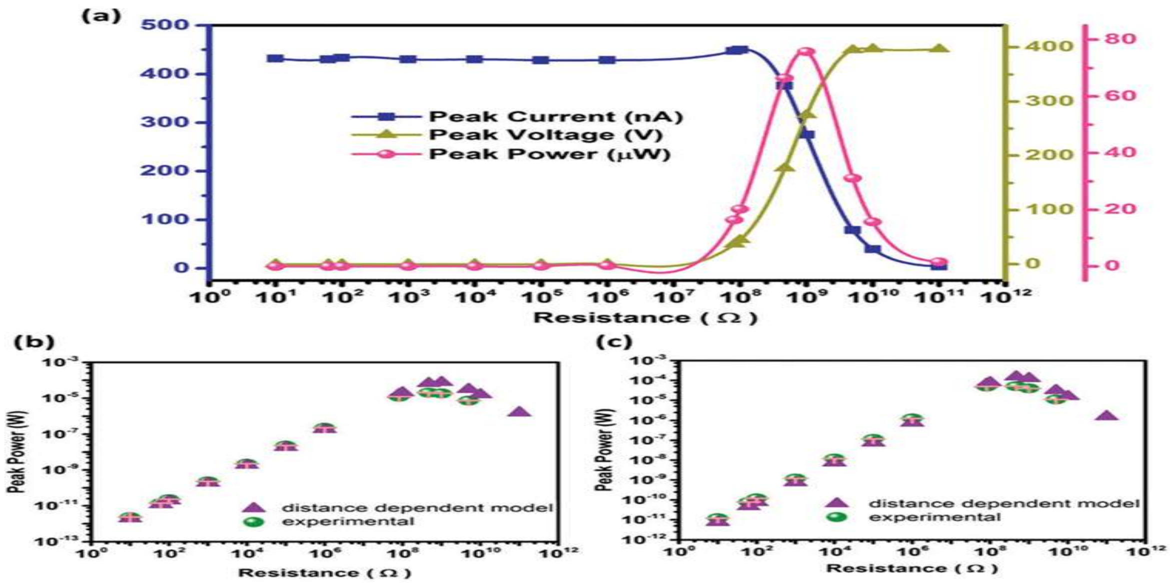

Fig.9: - The 3-working-region behavior of the TENG power output predicted by the distance-dependent model, against different load resistors (f = 1 Hz, H = 1 mm), shows the comparison of the experimental and predicted peak-power outputs under different resistances (a); f = 1 Hz (b) and f = 2 Hz (c), where H = 1 mm.

Voltage Regulator Circuit Diagram:

Robots receive power regulation usually through a voltage regulator; this is because when the robot is operating, it needs the power to be the same always. As batteries are used, the battery life decreases. It starts out with full voltage, 9 volts for a 9-volt battery, and decreases and decreases with usage. Unless stabilized, this would result in a robot that moves at different speeds, has different light brightness, and sensor readings, based on battery freshness. This can't be, regulate the voltage of the circuit voltage is used. Another reason for power regulation is that some parts of the robot need more power than other parts. For example, the DC motor your robot uses to move usually needs more power than an LED. The following circuit is the answer to the problem. This circuit can give +5V output at about 150 mA current, but it can be increased to 1 A when good cooling is added to the 7805 regulator chip. The circuit has overload and thermal protection, and the capacitors must have enough high voltage rating to safely handle the input voltage feed to the circuit.

1) *Parts:*

- C1 = 100uF-25V electrolytic capacitor, at least 25V voltage rating
- C2 = 10uF-25V electrolytic capacitor, at least 6-16V voltage rating
- C3 = 100nF-63V ceramic or polyester capacitor
- IC = 7805 regulator IC

2) *Circuit features:*

- Gives out well-regulated +5V output, output current capability of 100 MA
- Built-in overheating protection shuts down output when regulator IC gets too hot
- Very simple and easy to build
- Very stable +5V output voltage, reliable operation
- Easy to get components, uses only very common basic components

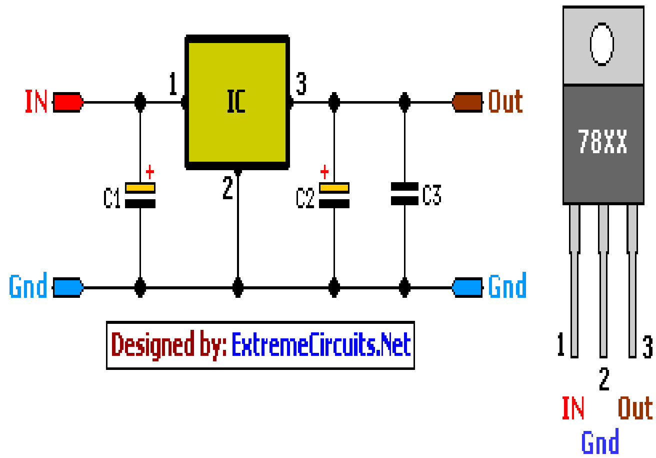

Fig.10: - Voltage Regulator Circuit Diagram

Storage Solution "lithium-ion battery"

Lithium-ion rechargeable coin cell batteries were fabricated by using $LiCoO_2$/carbon black/binder mixture on Al foil (1 cm in diameter) as the anode, polyethylene (PE) as separator (2 cm in diameter), the graphite/carbon black/binder mixture on Al foil (1.5 cm in diameter) as the cathode. The electrolyte (1 M $LiPF_6$ in 1:1:1 ethylene carbonate/dimethyl carbonate/diethyl carbonate) was injected inside between the anode and cathode before the coin cell was pressed firmly. The charging-discharging curves of these batteries were tested as shown in Fig.11, which exhibits a plateau voltage of ~3. 8 V [19].

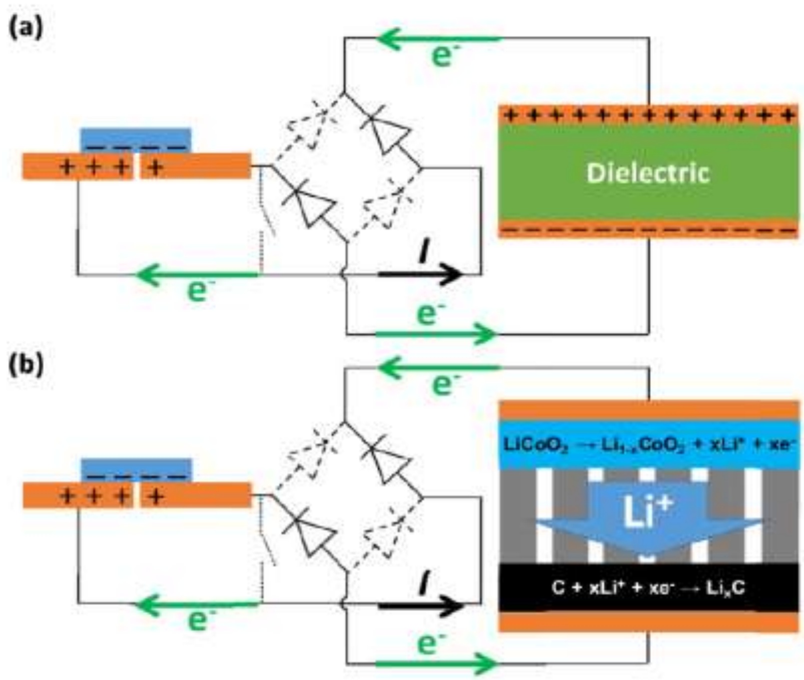

Fig. 11: - The charging process of a) a capacitor b) a fabricated the lithium-ion battery

Conclusions & Future Works:-

Harvesting energies from surroundings to build up self-powered sensing systems are very useful in our daily life. Triboelectricnanogenerator (TENG) has been applied as a fundamental new technology to revive the field of vibration energy harvesting and self-powered sensing, especially for low-frequency vibrations such as human motion, automobile, machine, and bridge vibrations. Triboelectricnanogenerators (TENGs) have attracted more attention, as a collection technology with characteristics of high reliability, high energy density, and low cost.

In this paper, both TENG-enabled vibration energy harvesting from robot's tires, and piezoelectric start-up circuit robot demonstrated. The open-circuit voltage and short-circuit charge of the TENG fixed in the rolling tire remain unchanged at the speed of the tire increases, and works on designing robot's circuit does not need any external reference battery using a piezoelectric startup circuit.

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