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Recent Trend in Biomechanical Energy Harvesting

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Abstract: *In this literature different biomechanical energy harvesters are reviewed. In the past years a lot of work reported on energy harvesting. Energy crisis is the main issue in front of human so it is essential to find new promising ways to fulfil the need of electricity. Wearable smart devices and small sensor require low electrical power so to power them biomechanical energy harvesters comes into picture. The innovative work done by the researchers in developing new biomechanical energy harvester is discussed and summarized.*

Keywords: Human Motion, Energy Harvesting, Biomechanical, Teng, Piezoelectric Harvesters, Electromagnetic Energy Harvesting, Wearable Harvesters

I. Introduction

The whole world is facing problem of energy crisis, pollution, global warming which significantly affects the human civilization. Green energy is a solution to the most of the problems. For small scale electronic applications, it is essential to reduce use of electrochemical batteries. Electrochemical batteries once discharged becomes unusable e-waste contributing to environmental pollution. So biomechanical energy harvesting comes up as a strong solution for electricity generation. Human body motion is most abundant source of low frequency energy. Which involves motion of limbs, flow of air through nostrils, expansion and contraction of chest and abdomen.[8][12] The research mainly focuses on extraction of maximum useful energy and convert it into electric energy. Human body can produce roughly 1 W of power from the motion involved during respiration.

Energy harvesting basically involves piezoelectric, electromagnetic, electrostatic, triboelectric generators. Which can convert mechanical energy into electric energy.[5] Now days, triboelectric nanogenerators are gaining much popularity in biomechanical energy harvesting. Triboelectric energy harvesters have their advantages as lightweight, flexible and high-power generation. They can be easily worn by person without compromising to comfort. Triboelectrification result when two dissimilar materials with different electron affinity comes in contact. This induce charge on materials and resulting in development of potential on the surface. The developed voltage is amplified by use of voltage multiplier circuits. The capacitor is charged with the voltage.

Most of the researcher have utilised combination of two or more energy harvesting principles for energy harvesting. These are also known as hybrid energy harvesters. For biomechanical application these hybrid energy harvesters are seen to be on par the excellence. Mechanical arrangement to capture motion improves the power output and reliability of the system[17]. Different small sensors and electronic devices can be operated with the biomechanical energy harvesters. The latest research carried out in the field of biomechanical energy harvesting is discussed in this paper.

II. Biomechanical Energy Harvesting

Recent work done in the field of the biomechanical energy harvesting is summarized in the literature.

Charanya and Chandrasekar 2020 [1] : - A biomechanical energy harvester using triboelectric nanogenerator as a swelf powering sensor is developed by the authors. In this work authors have demonstrated an alternative way to design a flappy tappy based triboelectric nanogenerator to harvest the energy produced during physical motion. Authors state that the proposed device is cost effective as well as eco-friendly. The maximum experimental voltage obtained was around 30 V and the current was of 1.5 μA. The device has capability to drive 100 LEDs. A prototype confirming to the theoretical model was manufactured and experimental voltage and current were recorded. The performance of Flappy Tappy based Triboelectric Nanogenerator was studied and electrical characteristics evaluated by digital oscilloscope. Authors derived the expression for open-circuit voltage and short circuit current. Maximum electric potential is attained when there is separation between layers induce more electron to flow creating triboelectric negative and positive charge on either side of device.

Guan et al 2020 [2]: - Authors proposed a breathable washable and wearable woven triboelectric nanogenerator using electro spun nanofiber biomechanical energy harvester. A novel woven structure WS-TENG was proposed. Authors have reported open circuit voltage with peak to peak value of 166 V and short circuit current of 8.5 µA with power density of 93 mW/m^2 at 10 MΩ. Electrospinning method was used to produce ultrathin long fibred. Stainless steel yarn serves as electrode. Experimental testing was carried out by authors for different materials in contact with woven structure and operating at differen.t frequencies. The voltage generated was observed. The prototype has ability to glow 58 LEDs. The study presented a new approach for self-powered textiles.

Panigrahi at al 2020 [3]: - Piezoelectric nanogenerator was proposed by author. which takes small mechanical energy as input and convert in into electric output. A PVDF thin film using solvent casting route was fabricated. All the properties related to the energy harvesting such as structural, morphological, di-electric, piezoelectric, ferroelectric was analysed. A piezoelectric nanogenerator was fabricated and results were checked for validation of the theoretical model.

Yun at al 2020 [4]: - An energy harvester to utilise mechanical energy walking to obtain electric output by using triboelectric nanogenerator technique. The electrical performance was enhanced by authors by using bi directional gear box. In result it amplified 1 Hz reciprocation oscillation into 700 RPM. The setup was manufactured by 3D printing method. Voltage multiplier circuit was used to amplify the output electric power. A novel tree type of shoe attachable triboelectric nanogenerator which effectively convert stepping into electric signal. 3 kV of voltage was obtained at the end of voltage multiplier circuit.

Gupta at al 2020 [5]: - In this paper authors have described the various approaches in biomechanical energy harvesting using different strategies to use piezoelectric or composite based devices.

Zhou et al 2020 [6]: -Authors have reported a small insole for high performance biomechanical energy harvesting from human motion. They also state the presented smart insole us waterproof and can work in any harsh environment. The principle for energy harvesting is based on a tube sandwich structured TENG for hind foot while maximized triboelectrification area for forefoot. The manufactured prototype was tested for maximum electrical power. The experimental results showed maximum voltage of 202 V and short circuit current of 15 µA. Authors state that smart insole is capable to illuminate 260 LEDs.

Zou at al 2020 [7]: - This review elaborates the different work conducted on different body parts which lead to mechanical motion and it is utilised by triboelectric nanogenerator to produce electrical energy. Review discuss about cost, wearability, integration, robustness, washability, power improvement and adaptability of the system.

Li et al 2020 [8]: -Authors have presented respiration driven triboelectric nanogenerator for biomedical application. The mathematical model of respiration phenomena is formulated. The work done during respiration is calculated and expression for mechanical power is obtained. Authors states that around 1 W of power is generated with respiration each minute. Different modes for TENG respiration-based harvester were discussed. The air flow from nose and expansion of chest or abdomen was considered for capturing energy.

Rana et al 2020 [9]: - Authors have reported the smart human interactive hybridized biomechanical nanogenerator. Authors also have proposed a novel technique to improve microstructure modification which lead to increase the harvesting efficiency. To improve surface charge density PTFE surface used reactive ion etching process. Finite element simulation of theoretical model was carried out in COMSOL Multiphysics. In which magnetic flux distribution of electromagnetic generator analysed and potential distribution of TENG was analysed. Optimization was carried out. Authors reported output power density of 185 W/m2 across a load of 1.6 KΩ at 20 m/s2 of acceleration under linear motion testing. Authors reported that the fabricated prototype can charge Li-ion battery of 18 mAh from 0 V to 3 V in 10 seconds and can operate multiple electronic devices simultaneously for 180 seconds.

Wu et al 2020 [10]: - Authors have reported a shape adaptable skin like liquid single electrode TENG using (aloe vera gel) organic gel and salt as liquid electrode. In this work authors have optimized the frequency for highest voltage output. Electrical potential was simulated in COMSOL Multiphysics with finite element analysis. Output voltage of 157.8 V and power density of 4.61 W/m2 was reported.

Yeh et al 2020 [11]: - Authors have reported a novel biomechanical energy harvester to carry out gait analysis by means of self-powered sensors using triboelectric nanogenerator. The study from the authors state the sensor can distinguish between normal gait cycle and pathological gait cycle. Authors claim that the proposed energy harvester will bring revolution in the field of gait analysis. Working with no use of external power supply like batteries and future scope of further motion analysis.

Cho et al 2020 [12]: -Authors have reports universal biomechanical energy harvester which extract energy from joint movement based in direction switchable triboelectric nanogenerator. In this work authors have stated that any kind of human motion can be utilised to operate TENG. A novel string type of TENG is proposed by authors. Which consist minimal weight and higher electrical output capacity. The work emphasises experimental manufacturing and testing of prototype. The analytical model was created and expression for the electric power characteristic was derived. The output performance of the energy harvester was optimized for different operating conditions like walking and running, elbow movement. Using daily motion as input the output of 2.6 kV was recorded by the authors.

Vivekananthan et al 2020 [13]: - Authors reported a small-scale hybrid biomechanical energy harvester working on TENG and electromagnetic generator. Authors have statedTENG has advantage of consistent charging behaviour, while electromagnetic generator has rapid charging behaviour. Thus, the system shows merits of the both. The biomechanical energy from walking and running and jumping is taken under consideration. The theoretical model was prepared and experimentally validated with the prototype. TENG showed 20 V and 300nA with 1mW/m3 power density. Electro-magnetic generator showed 2V and 10mA with 4mW of instantaneous power.

Wen et al 2020 [14]: - Authors have reported a novel superhydrophobic triboelectric textile for sensing and energy harvesting. The proposed textile has anti-humidity and quick recovery from high moisture. This is beneficial in formulating wearable TENG. Authors have developed a gesture recognising system based on deep learning. The reported harvester power density is of 0.18 W/m2 for walking, running, elbow bending, hand tapping movements.

Wang et al 2020 [15]: - Authors have proposed a new portable electromagnetic energy harvester mounted on shoes. In this literature the performance and the effect of energy harvesting device on wearer is key consideration fro evaluation. A lightweight biomechanical energy harvester is reported which is having 110 grams of weight. New energy harvester us compared with knee harvester and suspended load backpack harvester experimentally. Experiment is carried out to evaluate capability of energy harvester during different body movements at different speed and environmental conditions. Authors have reported 7.71 mW of power during waking and 5.28 mW during climbing stairs.

Fan et al 2019 [16]: - In this literature authors proposed a novel lightweight biomechanical energy harvester with high power density and low metabolic cost. Device consist a cable pully mechanism arrangement to convert revolute motion into utilizable for rotating generator shaft. Authors have created a dynamic model pf the mechanical system and electric system. The model is optimized to attain maximum rotation of generator shaft with high speed and low torque. Prototype confirming to the theoretical model was fabricated and experimentally validated. Authors have reported average 4.1 W of electricity produced.

Yan at al 2020 [17]:- Authors have reported a linear to rotary hybrid nano generator forhugh performance wearable biomechanical energy harvester. It is an low frequency energy harvester in which the voltage generated by means of human motion is amplified to 3.1 to 3.6 times at basic frequency. The electricity generated from electromagnetic generator was verified using COMSOL simulation software. Biomechanical motion induced magnetic charge and coil generates electro-motive force. Prototype confirming to the theoretical model was fabricated and concept was validated. Prototype was used to operate temperature sensor and humidity sensor.

He et al 2019 [18]:- Authors have proposed an enhanced triboelectric nanogenerator fabric by using piezoelectric material for application in biomechanical energy harvester. Authors state that the developed fabric is stretchable, durable and possess good air permeability and excellent reliability. The Piezoelectric triboelectric nanogenerator was able to produce 600 V and 17 μA and maximum reported power output of 1.11 W/m2 under 20MΩ load. The manufactured prototype was attached on different body parts like arm, knee, foot and the electric performance of the harvester was tested. Capacitor was charged with generator potential and further utilised to drive commercial electronic devices. Authors have carried out finite element simulation of electric generator for different states and experimentally validates.

Bao et al 2020 [19]: -An anti-freezing hydrogel based stretchable triboelectric nanogenerator for biomechanical energy harvester at sub-zero temperature was presented by authors. Authors have proposed a novel technique to prepare anti-freezing hydrogel by using one step radical polymerization of acrylic monomer in hydroxyethyl cellulose aqueous solution, it can sustain -69 ºC without freezing. When operated at 2.5 Hz of hand tapping anti-freezing hydrogel TENG has generated electric output as 285 V, 15.5 μA, 90 nC. Prototype shown enough power to illuminate 125 LEDs simultaneously.

Tao et al 2020 [20]: -Authors have proposed origami inspired electret based triboelectric generator for biomechanical and ocean wave energy harvesting. In this work author have utilised the sinusoidal vibration as well as impulse excitation. The novel double sided corona discharge method is used to enhance operational characteristics of electrat film. The manufactured TENG shows open circuit voltage of 1000V and short circuit current of 100μA. Maximum reported power was of 0.67 mW/cm3. Work consisted theoretical modelling and validation with experimental testing of prototype.

Shen et al 2017 [21]: - Authors have reports a humidity resisting triboelectric nanogenerator for high -performance biomechanical energy harvesting. The fabric for triboelectric generator was prepared with electro-spun technique and nano fiber membrane were tailored to enhance effect of vapour on electrical output. The ability of humidity resistance was improved. The maximum output delivered by the harvester was 345 V and 25μA. With power density of 1.3 W/m2 at 55% relative humidity. Prototype was capable to enlighten 400 LEDs simultaneously.

III. Summery and Outlook

Resent trend in biomechanical energy harvesting is reviewed in this literature. Different kinds of novel ideas of energy extraction from human body movement have been developed. In this Triboelectric nanogenerators are getting widely used for wearable energy harvester applications. These wearable energy harvesters have very high voltage output and are much efficient in powering low power devices and electronic sensors like temperature sensor, humidity sensor, motion sensor, heart rate monitoring sensor, etc. Hybrid energy harvesters show maximum power developed as it contains merits of all the included energy harvesting principles. Wearable textile TENG are getting more popularity. many of the researchers have opted for mechanical arrangement to capture the vibration/motion from joints during movement. These biomechanical energy harvesters with mechanical show efficient energy conversion. The main challenge in front of the researchers is that to extract maximum possible amount of energy from human motion and convert in into electrical energy with minimal losses. In this review it has been observed that hybrid energy harvesting systems are the future of power generation. In the near future of biomechanical and biomedical engineering the diagnosis of pathological motion of human body could be monitored by self-powered sensors with elimination of heavy batteries or external power supply.

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