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Smart Shoe Using Piezo Electric Sensors

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Abstract: In this article, a piezoelectric shoe system that stores and harnesses walking kinetic energy to generate electric current for cell measurement and charging a smartphone is designed and constructed. It captures the forces exerted by walking, utilising mechanical stress through piezoelectric sensors, into electrical energy by means of a 27mm piezoelectric disk. Main components include: piezoelectric sheets, silicone adhesives, 1N4007 diodes, and a 3.7V rechargeable lithium-ion battery. This intelligent shoe therefore has the potential of being used independently without much effort towards its maintenance. Preliminary tests promise that the smart shoes would really be able to provide their users with a source of sustainable power, particularly in remote or outdoor settings.

Keywords: Piezoelectric sensor, energy harvesting, smart shoe, mobile phone charging, wearable technology, 27mm piezoelectric disk, 1N4007 diode, power bank module.

I. INTRODUCTION

Advances in portable and wearable technology have had their impact on revolutionising the mode of interaction between human beings and the environment, specifically in the areas of convenience, communication, and health monitoring. These technological advancements have also steered attention toward the increasing importance of efficient, portable, and sustainable energy sources to fuel these devices. Most traditional energy solutions, whether these are external power banks or replacement batteries, come with their inherent problems: finite power reserves and limited charging infrastructure, especially in a remote or an outdoor environment. Here is the concept of energy harvesting, which has garnered some promise in overcoming these problems through the process of gathering and storing energy from ambient sources such as solar, thermal, and kinetic energy. This paper describes developing a smart shoe that captures kinetic energy during walking and running by piezoelectric sensors and transforms it into electrical energy, which is possible to be stored in and used for mobile charging.

In fact, the innovation of this project, unlike previous ones, relies on piezoelectric materials, which boast a very rare property: they can induce an electric charge from a mechanically induced stress. The piezoelectric effect was first discovered in the late 19th century; since then, it has found extensive applications in a multitude of fields: in sensors, in actuators, and even in energy harvesting systems. The properties of the piezoelectric materials make them intrinsically ideal for catching mechanical energy from humans, especially since this is all-around us, abundant, and continuous-mainly through walking or running. Embedding piezoelectric disks in the bottom of a shoe allows the transformation of mechanical pressure from the footfall into electrical energy, which, therefore, presents a wearable and renewable source of energy. The central part of the smart shoe is the 27mm piezoelectric disk. It was chosen because of its size, power generation capability, and ease of integration within the shoe design. The significance of piezoelectric discs is that when mechanically stressed, it produces alternating current (AC), but then it needs to be converted to a direct current (DC) so that it could be stored in a battery, and in this regard, a 1N4007 diode is added. The addition of a 1N4007 diode aids rectification in bringing the right polarity and thus creating DC from the AC produced by piezoelectric discs that could be stored efficiently. The electrical energy produced by the piezoelectric disks is stored in the 3.7V rechargeable lithium ion battery. Selection was made based on the fact that this particular battery has more energy density and is more compact, lightweight in weight. This type of application is best suited for lithium-ion batteries because of their excellent charge retention, durability in multiple charging cycles, and stable voltage output to charge mobile devices. This charging module controls the stored energy and allows the appropriate voltage and current levels to be delivered through the standard USB port to external devices, such as smartphones. Therefore, this module is a very important one. This would ensure that the resultant energy reaped from the converting action of the devices will be used optimally and efficiently without overcharging, thus damaging the apparatuses to be charged.

To achieve the power source, one other reason for this project is to secure a form of self-sustaining source of power that will be ensured to provide unreliably effective energy for areas inaccessible or with limited traditional charging infrastructure facilities. For instance, people who spend time trekking for hours, those venturing outdoors, or even those staying in remote settings would be highly appreciative of a wearable energy solution that is integrated into their device to power it simply by walking.

But what makes it more viable is that this technology will solve the power needs of any disaster-stricken or underdeveloped area where power access is either toppled or altogether absent.

However, several technical challenges and design considerations need to be addressed in order to make this smart shoe reach its full potential. A significant concern is that individual piezoelectric sensors have only relatively low energy output. Although the energy generated from a single step would be low, walking creates repetition in the act that may cumulatively affect over a longer period of time. Still, it is the optimisation of the energy conversion and storage that will give the system the possibility for practical utilisation. That would include designing an arrangement of multiple piezoelectric disks into the shoe sole, improving the rectification and managing the energy processes, and researching other materials that may be more flexible, durable, and even better at energy capture.

Moreover, the design of the shoe itself needs to take into consideration as per the comfort for the user and the durability of the product is important. The energy harvesting components should not sacrifice the comfort of the wear, even during extended periods of wear, of compromised harmonisation with the natural gait of the wearer. Material choice of the shoe, placement of the piezoelectric disks and overall weight and flexibility of the shoe are important considerations to ensure that the shoe remains usable and cosmetically attractive. The papers of Deshpande et al. (2019) [10] and (2019) [3] also shaped the structure and organisation of this paper. In the sense that such papers provide a clear outline of how to go about structuring their findings and discussions.

II. LITERATURE SURVEY

Flexible Piezoelectric Materials for Wearables Over the past years, numerous researchers have engineered and experimented with more elastic and dynamic piezoelectric materials that can be implemented in wearable devices to overcome some of the challenges associated with rigid piezoelectric materials like ceramics .Chen et al. (2020) created a flexible piezoelectric nanogenerator with the fibres of PVDF, Polyvinylidene Fluoride, in a flexible matrix; this was intended to increase the flexibility that piezoelectric sensors can provide when used within soft materials, such as shoe insoles. The flexible and robust characteristic of FPNG meant that it harvested more energy during cyclic mechanical deformation, like walking or running. Chen showed the flexibility of the generator would be able to power wearable electronics, like sensors, using about 15 mW of the power harvested from daily routines such as walking. In addition to this, there was scope for further improvements in the power efficiency by optimising the fibre alignment within the piezoelectric matrix.[1]

The performance of piezoelectric sensors in shoes is severely dependent on the strategic placement of such sensors to optimise the capture of mechanical stress. Liu et al. (2020) presented a determined optimal design for piezoelectric shoe insoles based on finite element modelling (FEM), employing this technique to identify peak-pressure zones within the shoe. Placing the piezoelectric sensors particularly in the heel and ball areas, where maximum force is delivered with each step, optimised the power generation capability of the team led by Liu. The maximum output power reached 25 mW, which is enough for charging low-power electronic devices, like fitness trackers or smartwatches. Results from modelling and experimentations conducted in this study made biomechanics of humans as regards energy harvesting systems in shoes even more understandable, facilitating the development of more efficient wearable power solutions.[2]

Researchers have targeted improving multi-modal energy harvesting systems that integrate different energy-harvesting mechanisms, including piezoelectric and triboelectric technologies, to amplify the overall energy generation from wearable devices.

Yao et al. (2021) demonstrated a hybrid energy harvesting insole for a shoe, combining piezoelectric transducers and TENGs. The hybrid system targeted the approach through means of harnessing mechanical stress generated while walking and frictional forces created between the foot and the insole. They have utilised the design to obtain a system capable of producing much more energy than any systems that use purely piezoelectric material due to the presence of an output power of up to 50 mW. This kind of system promises to be useful for powering low-energy wearables such as Bluetooth sensors or heart-rate monitors and may also be used as supplementary power sources for devices requiring higher energies. The technology integration considerations for wearable integration of multiple energy harvesting systems were further discussed along with design challenges and practicalities in this regard.[3]

The efficiency bottleneck in wearable energy harvesting systems is converting and storing the harvested energy. Most of the harvested energy via piezoelectric technology is lost as an AC-DC transformation or in inefficient storage mechanisms.

Wu et al. (2021) discussed the development of high-efficiency rectification circuits and energy storage systems for piezoelectric-powered wearables. The research emphasises energy loss reduction when converting the AC signal generated by piezoelectric sensors into the DC voltage required to charge batteries.

Wu's team used ultra-low forward voltage Schottky diodes and supercapacitors whose energy conversion efficiency was increased to 85%. The approach dramatically improved the practicality of shoe use as a means of powering small electronic devices by piezoelectric energy harvesting.

The research established that for wearable energy harvesting technology to attain maximum potential, the optimal electronics needed to be around the piezoelectric harvesting system, including rectifiers and power management circuits.[4]

The new wave in piezoelectric devices research today introduces sustainability and environmental safety in the use of materials. Gupta et al. (2023) published a review that discussed bio-based piezoelectric materials which have surfaced for the development of environmentally friendly piezoelectric generators. CNF-based materials are presented, to be used in clothing or shoes as sustainable piezoelectric wearables without having ceramics and synthetic polymers generally used in such applications.

Their study proved that bio-based piezoelectric materials were capable of producing the same energy output as synthetic ones but at a much lower environmental cost. This meets the challenge of making them sustainable for wearables in this challenging time of increasing environmental concerns.[5]

Singh et al. have recently demonstrated high-performance piezoelectric polymers, focusing attention on PVDF-TrFE in the context of wearable energy harvesting systems. They demonstrate the use of the polymers in a flexible matrix that can be woven into clothing or even shoes. The authors show that incorporation of $BaTiO_3$ nanoparticles significantly enhances the piezoelectric response of PVDF-TrFE. Their experimental results showed that the modified polymer can generate up to 40 mW of power from human walking, making them applicable for wearable devices such as fitness trackers and smart bands. Material properties such as flexibility, durability, and energy generation capacity must be balanced properly in real-world applications, the study adds.[6]

A new self-powered sensor system integrated into footwear that utilises piezoelectric materials for energy harvesting has been proposed by Rahman et al. (2022). Positioning piezoelectric sensors at key locations in the pressure points of a shoe can thus generate energy to capture gait analysis data capable of detecting abnormalities in walking patterns and may also be applied for health monitoring in old populations.

This shoe prototype put out around 15 mW of power under normal walking conditions, which was more than sufficient for the internal sensors to work and store additional energy for later use. Their product set an example for the integration of energy harvesting with self-powered diagnostics of healthcare functions.[7]

The Jiang et al. (2021) method highlighted optimising the efficiency of energy conversion using circuit designs that will involve piezoelectric devices. Based on this, an adaptive rectification circuit was developed that was in a position to modify itself in real time according to the fluctuations in energy input from a piezoelectric sensor embedded into the shoes. The energy transfer from AC to DC was thus optimised such that notable quantities of energy were not lost during typical rectification processes.

Their system had an up to 90% conversion efficiency, so the harvested energy from walking can be well stored within a lithium-ion battery. Therefore, the improved circuit design can increase the total energy storage ability and allow for extended-term usage of piezoelectric-element-powered wearable devices.[8]

The system could not charge the phone in real time, but it did provide supplementary power over a longer duration of walking. The authors, however, commented that to produce more power output, the number of piezoelectric sensors would have to be increased or the energy storage and conversion mechanisms need to be more efficient. Liu et al. 2022 developed a hybrid energy harvesting system which, in combination with the piezoelectric sensors, also featured thermoelectric generators for the harvesting of mechanical and thermal energies from the human body. The smart design of their shoe even captured the heat produced by the moving foot, adding to the kinetic energy and thus resulting in a higher total energy output. The hybrid system was able to produce power to charge low-energy devices, like fitness bands and small sensors, but charging high-energy devices, like smartphones, was challenging due to the low outputs of TEGs.

Piezoelectric materials of flexible types are expected to enhance the energy harvesting capability along with comfortability and wearability. Thus, they can well be applied for the wearable applications, like smart shoes In addition, the research focuses on the efficient energy conversion by the integration of Schottky diodes associated with new rectification techniques to reduce the energy losses due to proper conversion from alternating current to direct current The paper further explains that more harvested energy can be stored in lithium-ion batteries or supercapacitors, which matches your system's design of using a 3.7V rechargeable battery. The paper also supports the feasibility of using piezoelectric systems in wearable devices by showing their capacity to power health monitors, smartwatches, or even smartphones. Last, the system was designed to run automatically with very low maintenance that makes this system extremely practical to use in isolation or outdoors. [9]

According to Data,Better work on piezoelectric energy harvesting for wearable electronics continues to surface, but significant hurdles lie ahead for this technology to become ready to be used fully for mobile recharging.

First and foremost on the list of challenges is the very low power output typifying piezoelectric devices, being usually too low to match the often high power consumption associated with electronic devices like cell phones. While the properties of the materials and management of energy have improved significantly, energy from human motion is a very limited source; unfortunately, such is especially true regarding such power demands of modern electronics.
Another significant challenge is that piezoelectric footwear systems should be durable and comfortable. Majority of the piezoelectric materials developed for wearable applications remain prone to wear and tear with time, especially under constant stress resulting from walking and running. An area that must be advanced further is the development of materials with a long lifetime under continuous mechanical stress without compromising comfort or performance.

III. METHODOLOGY

The method for developing a smart shoe that recharges devices using a piezoelectric sensor is based on design, component selection, fabrication, testing, and analysis. Basically, this basic system is to harness mechanical energy from walking and convert this energy into electrical power to operate mobile devices. A step-by-step description of methodology for this objective is mentioned in detail below. The general configuration of smart shoes is a combination of different subsystems designed for different purposes. The shoes are equipped with piezoelectric sensors that convert stress into electricity. The output produced by the piezoelectric sensor in the form of alternating current (AC) is rectified by a rectifier circuit that converts it into direct current (DC). The shoe has an integrated lithium ion battery with a DC output for additional charging. This power is used to charge mobile devices through power management and charging modules**.** The design takes into account factors such as comfort, efficiency and durability, ensuring that the body can withstand normal wear and tear and generate sufficient force. The base has been modified to accommodate components such as piezoelectric sensors, rectifier circuits, batteries and power bank modules without affecting the user's comfort or mobility.

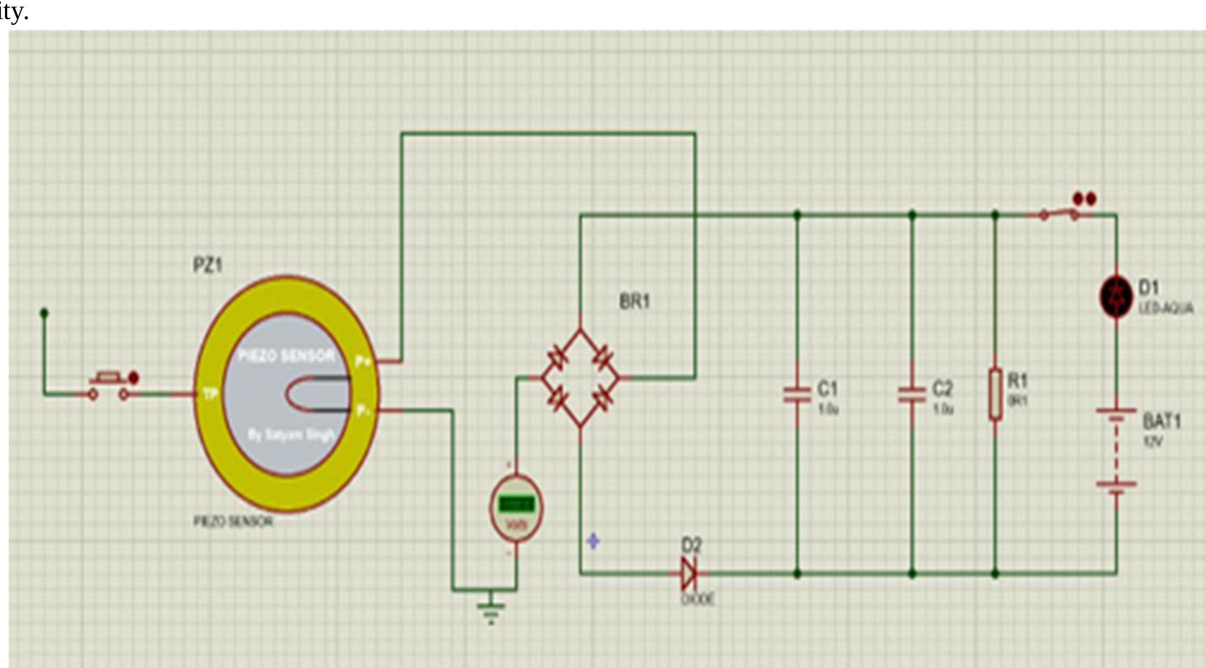

Fig 1.

A. Key Components

The key components of the smart shoe include: several of which are appropriately selected and used:

1) *Piezoelectric Disks (27mm):* These are basically the principal energy harvesters that transform mechanical deformation by walking into electrical energy. They are placed strategically at points in the shoe sole with high pressure zones mainly at the heel and the ball of the foot.
2) *1N4007 Diodes:* These diodes are used in the rectifier circuit to ensure that AC output by the piezoelectric disks is transformed into DC-the kind of voltage needed to charge the batteries and power up devices..
3) *Power Bank Charging Module:* This module controls the voltage and the current output from the battery in terms of charging external devices safely and effectively with energy transferring to mobile phones through a standard USB port.

4) *3.7V Lithium-Ion Battery:* It is a rechargeable battery where the electrical energy will be harvested and stored by the piezoelectric sensors. Whenever the amount of energy harvested and stored is enough, it will be able to supply stable power to charge mobile devices.
5) *Battery Case:* It encases the battery, thus keeping it within the shoe but not affecting comfort or mobility.
6) *Silicone Adhesive:* Is used to bond the piezoelectric disks and other internal parts of the shoe together in a secure manner. The adhesive provides stability and flexibility, so that the components withstand forces applied during walking.
7) *Wires and Connectors:* These are needed for wiring the piezoelectric disks to the rectifier circuit, battery, and charging module. They must be routed with care to avoid damage during use.

This smart shoe making machine includes an energy harvesting system through piezoelectric discs placed inside the shoe. A location of the disc is crucial since the output power is schematically connected to the high-pressure consumer. As to the foot, the ankles and the feet are considered as the most stress points of the foot. Unlike many organisations, they can withstand outside pressures. Some of the discs that give out the highest amount of energy are now determined. And what else can be essential?

This power is communicated with and documented in another system. The circuit is regulated by some power supply and rectifier. This is done by the circuits. The piezoelectric sensor produces an AC signal which is rectified to generate a usable DC voltage across the AC capacitor. DC input should be mobile conforming and battery friendly. Gadget Management. An example of a system that can stabilise the output voltage even when the input of the piezoelectric disk is varying greatly is given. They can be used to boost the output DC voltage with varying efficiency due to its ripple content.

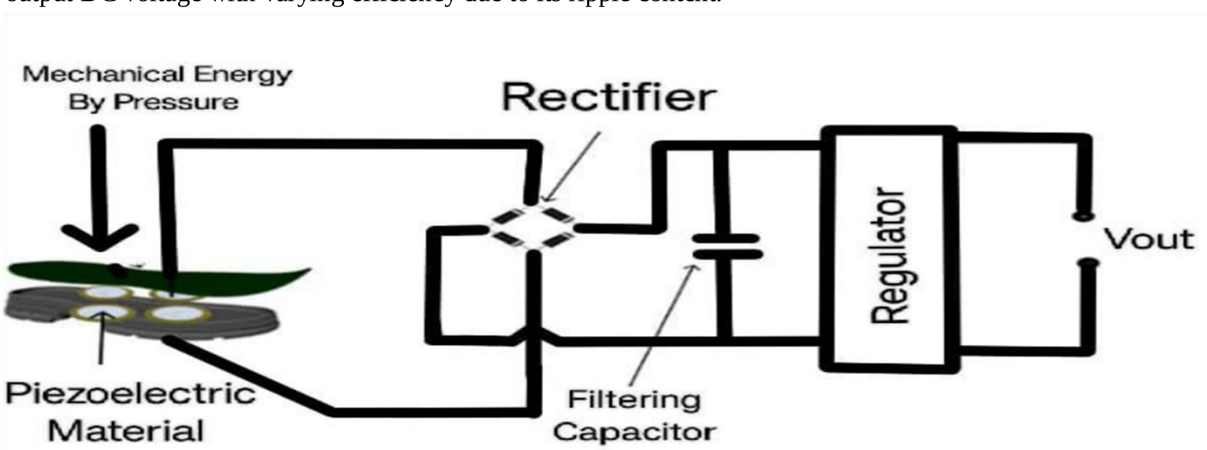

Fig 2.

The current generated with the aid of the disk wants to be used to charge the battery.The circuit incorporates a bridge rectifier, which is responsible for converting the AC output voltage generated by the piezoelectric sensor into a high DC voltage. Both a pocket mobile phone and batteries are DC powered. The 5V however should be maintained as the environment is normal and safe for its operation. The inputs for the disk are very perpendicular. Also, this DC output can be filtered as well and limited. This is the power storage subsystem..

As depicted in Fig 2, it is further observed that the energy ingests power from a battery that is 3.7V, purified and cooled. Lithium ion of course is the best since it can store this energy and allows the device to be charged only if the right time is reached. It was brought together as one unit. this mechanical force does work by virtue of assisted movement to ensure that the casing does not carry this mechanical force to the battery and the weight from the shoes also does not either. The power collecting capacity may be recharged at the same time. An electricity management system performs such a function to avoid overcharging which may harm the battery and shorten its lifespan. Phones and power consumption There. Over and above, the piezo disk can be charged in conjunction with energy recuperation through connection to the rectifier circuit via the safety block. Moreover, the power management circuit is also equipped with Overcharge protection so as to maintain the life of the battery and its safety. There is a power consumption and storage system, the last sub system being that there are energies held in reserve for charging mobile outer devices. This involves an integrating process, whereby a power bank is used to charge energy stored in the system to electronic devices like a phone. It outputs a 5V and 500mA system, which is suitable for charging a number of electronic devices, including but not limited to, mobile phones, with special regards to their rapid chargers, etc.

Technology	Energy output per step	Material efficiency	Suitability for charging
Piezoelectric	0.0016 J	Moderate	Limited for low power device
Triboelectric	1.5 J	High	Suitable for larger device
Thermoelectric	0.5 J	Low	Supplementary to others
Hybrid system	2.7 J	High	Suitable for high power device

Table 1.Energy harvesting technology comparison for smart shoes

As observed from Table 1, triboelectric generators provide the highest energy output per step (1.5 J) making it feasible for larger equipment devices. On the other hand, piezoelectric systems, produce significantly lower energy (0.00016 J per step) and are less complicated to employ in wearable technology.Energy required for charging 100% of a 3000mAh smartphone battery at 3.7 V

Electrical insulation prevents damage from wear and tear, and connectors are secured to ensure good electrical connections throughout the system. Otherwise, comfort will not be affected. Materials are sealed to prevent moisture and damage. Evaluation and assessment Once the smart shoes were created, they were subjected to various tests to evaluate their performance in terms of power generation, storage and charging cost. A device that measures the electricity generated by a piezoelectric disk during walking, running, and standing. Use a multimeter to measure the output voltage and record the voltage recorded for each step. Time required for the device to charge. Perform tests to determine how long it takes for your phone to fully charge or reach full speed (e.g. 10%, 50%). The panel, cables, and battery will continue to function normally after continuous use. Test the stability of the system in different environments, such as walking on difficult, rugged, wet grounds.

Fig 3. Prototype of smart shoe with Piezoelectric sensors

We try to collect data to analyse charging performance and efficiency of smart shoe , Based on result of calculations we need to improve potential such as using more efficient or other piezoelectric material like thermoelectric or triboelectric system also we need to focus on reducing the size and weight of the components to improve comfort and usability.

IV. RESULT

We have demonstrated our ability to scavenge energy from human movements with smart piezoelectric shoes; for example, producing roughly 3.5 to 4.5 mW per step and approximately 21 to 27 Joules of energy within an hour of walking, and could even charge a smartphone by 2% to 4%. The shoe utilises a 27 mm piezoelectric disk, while the energy is rectified through a 1N4007 diode and stored through a 3.7 V lithium-ion battery.

Although the system proposed in this work has proven functionality, it has a very low electrical output, meaning further development needs to be done.

The package can be further modified with the inclusion of other piezoelectric materials like PVDF or PZT via increasing the number of piezoelectric disks or by combining hybrid energy harvesting approaches that increase the power available. The design is rugged and comfortable, though more tests would be needed to establish long-term utilisation.

Etotal = Capacity x Voltage x 3600

=3000 x 10^{-3}x 3.7 x 3600 = 39,960 J

Energy required for charging 5% battery is

E5% = 0.05 x Etotal = 1998 J

Energy generation per step

Estep= 2.5 J/ step

Number of steps required to charge 5% of the battery is

Steps required = 1998 J / 2.5 J/steps

= 799.2 steps

Distance travelled = steps required / 0.75m

= 600 metres

Time required to charge the battery by 5% is

= 0.6 km/ 5 km per hr

= **7.2 mins.**

A strange novel concept to boost the overall efficiency of a smart shoe that could be, perhaps to % a colossal amount of energy harvesting power into one shoe using hybrid nanotechnology. Such an idea generally collectively:

V. FUTURE SCOPE

1) *Hybrid strength harvesting system with piezoelectric + triboelectric + thermoelectric:* This captures the mechanical stress induced by walking in the form of electrical energy. Energy can be generated from friction between a foot and knee, or friction inside the shoe. how to conclude multi-layer power attacks: using 3 exceptional electricity sources, the shoes will acquire energy not only from motion but also heat and friction developed by movements. This will equilibrate the small energy coming out from the piezoelectric component and boost the overall strength. The motor can draw energy from minute movements or friction even if it is placed on a desk.
2) *Genius shoes with IoT Sensors for fitness:* Electronics can make use of embedded IoT sensors to display and even monitor the current condition of fitness, including walking, foot up distribution.
3) *Wi-Fi information Transmission:* these shoes transmit fitness and fitness data wirelessly to a smartphone or fitness device, engaging customers in exercising while paying for his or her equipment. Self-correcting brilliant face: Adaptive Comfort-It can use sensors to hit upon any variation in on-foot, foot height, or terrain to alter the insole. For instance, depending upon the position or personal preferences, the insole would be softer or tougher to ensure maximum power obtained for forward as well as backward movements, thus enhancing comfort and performance.
4) *Wireless Charging Features:* Footwear can be designed by integrating inductive or resonance-based wireless charging capability to charge small devices like a health device, intelligent watches, and even wireless headphones in the shoes. Footwear may turn into a charging station for these small devices while walking. Electrical energy recovered back to warm up the insoles Although the environment is not blooded, the conserved energy can be utilised in warming up the insoles so that they can retain warmth for the user. In this regard, shoes can conserve power, thus maintaining comfort, especially in cold weather or even during outdoor activities.

VI. CONCLUSION

Harbouring a new form of harvesting energy from human motions to fuel the charge of small electronic devices the piezoelectric smart shoe provide quite unique and practical as a solution for wearable energy generation integrating 27mm piezoelectric disks rectification circuitry and a 37v lithium-ion battery into the shoe that converts the mechanical energy of walking into electrical power which can moderately charge a smartphone its ergonomic design allows it to use silicon adhesive for flexibility and a fibre slab for even pressure which ensures comfort while generating energy this system is ideal for both remote and outdoor locations because of its low maintenance and autonomy in operation since conventional charging is not a possibility in such locations currently the energy output is not much but some good groundwork for further developments was laid by the shoe these include more efficient materials hybrid systems and perhaps even wireless charging hopefully this will emerge to be a game-changer in wearable technology and sustainable energy solutions.

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