DESIGN AND DEVELOPMENT OF A RANGE OF DEVICES UTILIZING ENERGY FROM HUMAN FOOTFALLS

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Abstract

The major problem in this world is energy deficiency. Demand for electricity is projected to increase in the future. The growing population could be a considerable resource for an idea to generate electricity by utilizing the rich source of energy from human footfalls. When person walks, he loses energy to the surface in the form of impact and vibration. This energy can be tapped and converted to usable form of electrical energy.

The aim of this project is to create a device that harvests unutilized human footfall energy into usable form of electrical energy. Piezoelectric material is used to convert this ambient footfall energy into electrical energy. The project begins with research study on piezoelectric materials and their applications. Survey was conducted at high density public areas like railway stations, malls and theaters. Design research methods like market study, user study, QFD and PDS were adopted to derive the technical features of the product.

Based on research, three design concepts were generated considering functionality, ergonomics and safety. One concept finalized for detail design and mock-up modelling. Mock up model was created with scale of 1:2 for product validation. And as a proof of concept full scale working prototype was developed.

Final chosen concept is a play equipment with lights designed for children to function without an external power source. The system starts functioning when children step on the tile, piezo discs are activated and generate electricity. This is connected to the compact step-up transformers and from there to LED lights. So this makes the children to play around it. The design is circular in order to give continuity using a circular path and provision made for easy assembly and disassembly. Barriers are provided on the side for safety for the children from falling down. The surface texture of the tile chosen is mat finish as this enables a firm grip when children walk or run on it.

Key Words: Energy harvest, footfalls, piezoelectric, children play equipment, ergonomics

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Nomenclature

mm	Millimeter
mv	mili volts
V	Volts
µa	Micro Amperes

Abbreviations

PDS	Product Design Specification
QFD	Quality Function Deployment

1. INTRODUCTION

The usage of traditional power generation method such as burning of coal, wood, diesel etc. is continuously consuming our natural resources such as fossil fuels. The reason beyond this is increase in demand for power has exceeded due to the growing population. Nowadays people have begun to use electricity from renewable sources, like windmills, hydro energy, and solar energy, but these have some limitations in the process of producing electricity. For example initial investment, efficiency depends on the environment etc.

The growing population could be a considerable resource for an idea to generate power by utilizing the rich source of energy from humans. So it is desirable to identify the everyday activity of a human, to harvest energy. By this, a new method has been found to generate electricity is from walking.

Walking is the most common activity in day-to-day life. When person walks, he loses energy to the surface in the form of impact, vibration, sound etc., due to the transfer of his weight on to the surface, through footfalls during every step. This energy can be tapped and converted in the usable form such as in electrical form. The purpose of this project is to create a device that harvests unutilized human footfall energy into usable electrical energy.

1.1 Sources of Electrical Power Generation

Following types of resources are available for generating electrical energy; this list can be broadened to include some more up-coming resources. The following are the popular and potential resources.

Conventional Sources

1. Thermal (from coal powder)
2. Nuclear (produced through nuclear fusion and fission process of radioactive elements)
3. Hydro Electric (generated by the flow of water through turbine)

Non-conventional Sources

1. Wind (kinetic energy of the air)
2. Solar-PV (From solar radiation)

2. LITERATURE REVIEW

Literature survey involves the summary of existing research; some of the patents and published journals are referred.

2.1 J. M. Donelan, Generating Electricity during Walking with Minimal User Effort [1]

This invention is related to generating electricity during walking with minimal human effort. The device harnesses the power of the human gait by tapping the natural braking motion at the end of every stride. The energy harvester device mounts at the knee and selectively engages power generation at the end of the swing phase, thus assisting deceleration of the joint (Figure 1).

An average of 5 watts of electricity can be produced while walking with one device on each leg, which is 10 times that of shoe mounted devices. The cost of harvesting the additional metabolic power required to produce 1 watt of electricity is less than one-eighth of that for conventional human power generation.

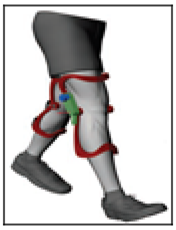


Fig. 1 Energy Harvesting Device [1]

2.2 S.S.Taliyan, B.B. Biswas, R.K. Patil, Electricity from Footsteps [2]

The device developed at the Reactor Control Division. The energy generated by this device can be stored in a 12 V lead acid battery. A 100 watt, 230 volt bulb was connected to the battery through an inverter. The device was operated by persons walking over to it. The bulb automatically lights up when the battery reaches its full voltage. The bulb remained lighted till the battery was exhausted as shown in Figure 2. If there is continuous movement of pedestrians over the device, the bulb can be kept lighted continuously.

Fig. 2 Footstep Electric Converter Device [2]

2.3 Shunmugham Rajasekara Pandian, Pneumatic Human Power Conversion System based on Children's Play [3]

When large numbers of children play in a playground, part of the power of their play could be usefully harnessed resulting in large energy storage. This stored energy can then be converted for basic, low-power, applications in the school such as lighting, communication, or operating fans. Energy can be produced through the use of pneumatic (i.e., compressed air) systems such as cylinders, motors, valves, and regulators for the conversion of human power of children's play in school playgrounds and other public places. The energy of the compressed air can then be converted to electricity for purposes such as lighting and communication. This provides a low-cost, low-resource means of generation of electricity, especially for use in developing countries.

2.4 Ming-Hsiang Yeh, Electricity Producing Shoe [4]

An electricity producing shoe comprises a shoe body including an electricity-producing module and an electricity generator mounted therein. The electricity producing module includes a rack, first and second gears, and a spring buffer that mounts between the first and second gears. The first and second gears are engaged with the rack and an axial gear of the electricity generator respectively. The electricity generator has an electricity output terminal connected to an electric device of the shoe body. As a result the rack drives the first gear and the second gear drives the axial gear of the electricity generator by means of normal stepping motion of walking for producing electric power and thereby supplying the electric power for the electric device (Figure 3).

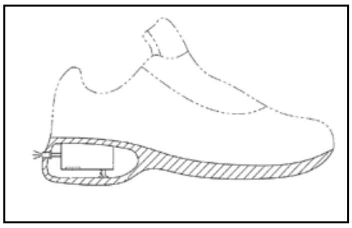


Fig. 3 Electricity Producing Shoe [4]

2.5 Summary of Literature Survey

Different technologies available to harvest energy from human footsteps, like using gears, rack and pinion, piezoelectric materials and compressed air etc.

Based on the study of patents and journals, there is a scope for below mentioned points.

1. Simplified mechanism
2. Easy serviceability
3. Ergonomic study
4. Suitable for high dense public areas

3. PRODUCT STUDY

3.1 Product study and Findings

Product study conducted for existing energy harvesting devices. Product study done through research and concluded that currently there are no standard devices for harvesting energy from human footfalls in India. Some of the problems identified in existing products and are shown in below Figures.

In Figure 4, safety is not taken care. When person walk thorough can fell down due to improper cable housing and needs to be addressed.

In Figure 5, due to its heavy size it requires lot of space and also installation and maintenance is difficult. Also cost of the product is more.

In Figure 6, Ergonomics is not considered and also the mechanism is complicated. The cost of product increases because of the difficulties involved in manufacturing and assembly.

Fig. 4 Safety Not Addressed [5]

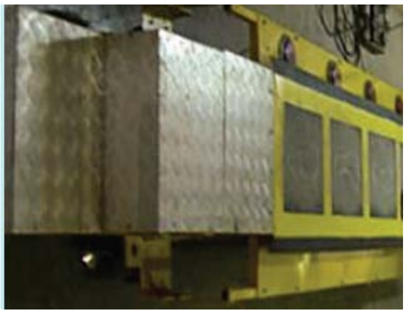


Fig. 5 Installation and Maintenance [2]

Fig. 6 Complex and Expensive [2]

4. MARKET STUDY

Market study conducted for energy harvesting device from human footsteps. There are very few energy harvesting products available in western countries (Figure 7).

Fig. 7 Energy Harvesting Devices

In an average lifetime, a person takes 150 billion footsteps; it's enough energy to power a house for three weeks [6]. So the renewable energy from footsteps is experiencing a rising demand in the coming years. This provides the manufacturers for new opportunities and competency in the emerging energy segment.

4.1 Manufacturers of Energy Harvesting Devices

1. Pavegen
2. Instep Nanopower
3. Energy Floors Limited
4. POWERleap Inc.

In terms of revenue Pavegen is expected to double to £1million this year [7]. And Instep Nanopower states that the potential market for this technology is very broad and includes both civilian and military segments with the total value over $ 17,000 million [8].

Largest installation of Pavegen energy harvesting tiles to date produces 4.7 kilowatt hours of energy during the Paris marathon, enough to power a five watt LED bulb for 940 hours, or 40 days [7]. Energy harvesting floor in the Busch Campus Centre at Rutgers University, harvested 0.34kWh/50 tiles daily (Figure 8).

4.2 Technology to Harvest Energy from Footsteps

Pavegen is adopted gears and magnetic fields technology, Instep Nanopower shoes uses liquid metal to generate power from walking, Energy Floors Limited uses electro-mechanical system to harvest energy, POWER leap Inc. adopted smart floor's core technology uses thin-film of piezoelectric device.

Different manufacturers adopted different technology for the energy harvesting device. But piezoelectric technology is very cost effective and user friendly.

Fig. 8 Energy Harvesting - Paris Marathon [7]

5. PRODUCT ENVIRONMENT STUDY

Conducted survey at heavy density public areas, where, human population is high like, railway stations, malls, theaters and metro stations, to observe pedestrian movements. This observation helped in selecting the area for product to get maximum footfall (Figure 9).

Observation showed that everyone should pass through the metal detector for the sake of security reason. Metal detector was found in all the places, wherever human population is high. So by placing the energy harvester near the metal detector will capture the more footsteps.

Fig. 9 Population at Malls and Railway Stations

6. ERGONOMIC CONSIDERATIONS

The ergonomics plays major role in the usability of the product. Every user is different from each other with respect to height, hand length, hand breadth, shoulder height etc. These things will affect the handling of the product and the user might feel uncomfortable if not designed effectively.

6.1 Ergonomic Postures [9]

Children between 5 to 10 years anthropometric data is not covered in data handbook, so the data collected by taking measurements of required parameters like foot length, foot breadth, forward step length and maximum body breadth. Measurement took from 25 children from different localities of Bangalore. Children having minimum and maximum percentile dimensions are visually selected for taking measurements as shown in Figure 10.

	Minimum	Maximum
Foot Length	210 mm	220 mm
Foot Breadth	95 mm	115 mm
Forward Foot step Length	280 mm	310 mm
Body Breadth	340 mm	370 mm

Fig. 10 Children Anthropometric Data

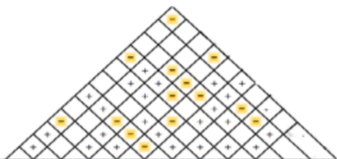
7. SCOPE OF IMPROVEMENT

1. Good aesthetics
2. Simplified mechanism
3. Serviceability
4. Easy assembly
5. Safety
6. Ergonomics
7. Environmental friendly
8. Should be innovative

8. QUALITY FUNCTION DEPLOYMENT (QFD)

QFD is done to convert customer needs into technical requirements. QFD helped to prioritize the customer needs which are identified during research. Table 1 shows QFD House.

Table 1. QFD House



Column #	1	2	3	4	5	6	7	8	9	10	9	10
Direction of Improvement												
Functional Requirements / Customer Requirements (Explicit and Implicit)	Aesthetics	Color	Ergonomics	Size	Weight	Price	Material	Safety	Quality	Mechanism	Battery	Maintenance
Product should be visible	●	●	○	○	▽	▽	▽	▽	▽	▽	▽	▽
Easily affordable	▽	▽	▽	▽	▽	●	●	▽	●	○	▽	○
Working in all environment	○	○	○	▽	▽	▽	●	●	●	●	●	○
Generated power should not affect people	▽	▽	○	▽	▽	▽	●	●	○	▽	○	○
Long life	○	○	▽	○	○	●	●	▽	●	●	●	○
More output	▽	▽	○	▽	▽	○	○	▽	●	●	○	○
Should capable of store energy	▽	▽	▽	▽	○	○	▽	○	○	○	●	▽
Should with stand load	▽	▽	○	●	●	▽	●	○	○	●	▽	▽
Easily replaceable	▽	▽	▽	▽	▽	○	▽	○	▽	○	○	●
Max Relationship	9	9	3	9	9	9	9	9	9	9	9	9
Technical Importance Rating	287.76	271.43	222.45	324.49	251.02	300	504.06	381.63	418.37	540.82	410.2	312.2
Relative Weight	8%	8%	6%	9%	7%	9%	14%	11%	12%	15%	12%	9%

QFD analysis is done by plotting graph with percentage of weightage against features. This helps to understand the key and supporting features to be considered while conceptualizing design. Figure 11 shows QFD matrix.

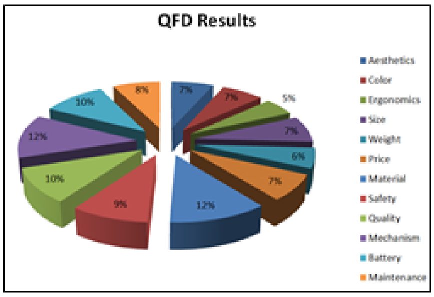


Fig. 11 QFD Matrix Results

9. PRODUCT DESIGN SPECIFICATION (PDS)

PDS is derived based on QFD matrix and analysis. PDS converts required features into targeted values and numbers to design develop the require product to meet customer requirements.

Here the PDS is generated based on the weight factor derived from QFD results and shown in Table 2.

Table 2. PDS

Product Design Specification (PDS)		
Sl. No	Description	Specification
1	Product name	Piezo Energy Harvester
2	Area of use	Malls, Theaters, Railway stations
3	Size	300x300x100mm (Proof of concept)
4	Approximate weight	6 to 10kg
5	Age group	Adults, Children age group between 5 to 10 years (for Gaming device)
6	Material	Plastic, Wood and Fiber
7	Maintenance	Once in a month
8	Aesthetics	Should be visible in all lighting conditions
9	Color	Bright colours
10	Quality	Should meet customer needs
11	Product Life span	1 year
12	Ergonomic	Should consider maximum percentile dimensions
13	Battery Type	Super capacitors bank
14	Market	Indian Context
15	Safety	Surface should not be slippery
16	Price	Approx. 5000/- INR
17	Package	In cardboard box with Sponge

10. CONCEPT GENERATION AND SELECTION

Based on PDS, three concepts were generated to meet the design requirements.

10.1 Concept-1

The first concept generated based on the findings from ethno study, it is observed that everyone should pass through the metal detector. So by placing the energy harvester with metal detector can capture maximum number of footsteps and ends up in getting more electrical energy (Figure 12). The output energy can be stored in super capacitor bank, which is connected to the energy harvesting device and this energy can be used for later applications.

The design is made detachable considering ease of handling and transportation from one place to another. Side frames are bolted together and when not in use or want to transport it is very easy and requires less space. Pocket is provided in the platform to assemble the energy harvesting tile. Platform side plates have swing movement and can be easily disassemble.

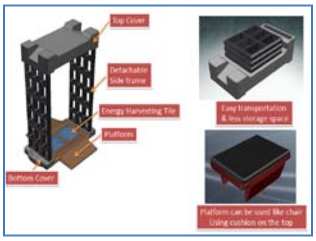


Fig. 12 Concept 1

10.2 Concept-2

The second concept is generated considering the population goes to the cinemas weekly. Now a day's people come to cinemas to maintain the cinema as a form of popular culture and get social experience. More than 30 percent of people come to malls will go to watch movies in cinemas. So by placing the energy harvester tile in the walkways can capture more footsteps and generated electricity can be amplified using step up transformers and store in super capacitors bank as shown in Figure 13. This electrical energy can be used for lighting application inside the theaters, like lightings along the walkways etc.

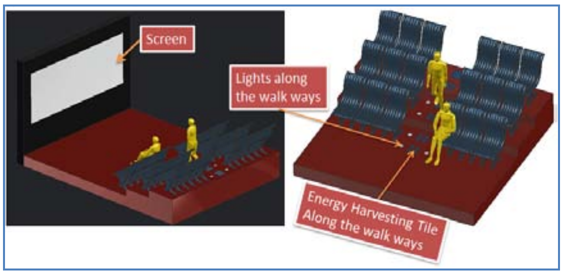


Fig. 13 Concept 2

10.3 Concept-3

Concept 3 is play equipment with lights designed for children to function without an external power source. The system starts functioning when children step on the tile, piezo discs are activated and generate electricity. This is connected to the compact step-up transformers and from there to LED lights. So this makes the children to play around it. The design is circular in order to give continuity using a circular path. Barriers are provided on the side for safety for the children from falling down. The surface texture of the tile chosen is mat finish as this enables a firm grip when children walk or run on it. Each tile is given provision for easy assembly and disassembly (Figure 14).

10.4 Mechanism - Proof of Concept

Two concepts generated to prove out the working principle, see Figure 15. Rack and spring actuation method is adopted in both concepts.

In 1st concept piezo assembly is placed vertically and rack creates vibration when spring actuation happens, which is mounted on to the top plate, refer Figure 15. In 2nd concept, series of piezo are glued on to the surface of the bottom plate, and works when nylon bars apply mechanical force due to spring action. 2nd concept gives less output compare to 1st concept, so 1st concept is chosen for prototype as a proof of concept. See Table 3.

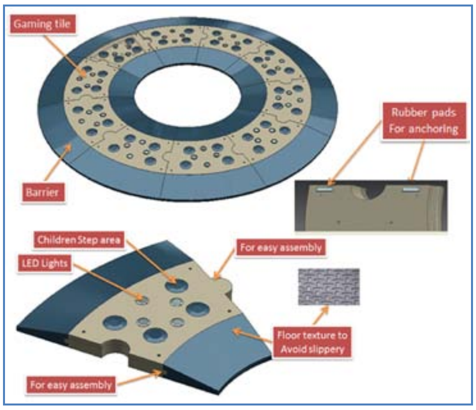


Fig. 14 Concept 3

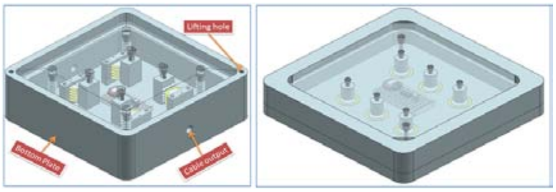


Fig. 15 Concepts 1 & 2

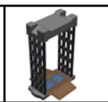
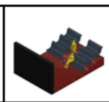
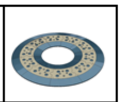
Table 3. Output of Energy Harvesting Tile

Voltage	Current
1 Pezo = 500MV	1 Pezo = 10 µ A
Total Pezo used 20	Total Pezo used 20
Power generated 500X20=10000MV	Power generated 10X20=200 µ A
= 10 Volts	Power =Volts x Current
	Power = 10 X 0.0002
	Power =0.002 watts

10.5 Concept selection

Concept selection is done based on weighted ranking method. Below are the points given to the each criteria. This method simplifies the selection of final concept. Concept-3 is selected as final concept based on points (Table 4).

Table 4. Weighted Ranking Method

Concept Scoring			
Selection Criteria	**Rating**	**Rating**	**Rating**
Aesthetics	2	3	4
Safety	3	2	3
Ergonomics	4	2	3
Mechanism	3	3	4
Cost	2	3	2
Total Score	14	13	16
Decision	Discard	Discard	Develop

Final concept was selected based on the weighted ranking method to make a 1:2 scaled mockup model along with drawings.

11. DETAIL DEISGNING

Concept detailing done in Unigraphics software, concept detailing is required to proceed it for manufacturing. Detailing conveys the information about tolerance, fits, what material used, what is the requirement of part and surface texture details to the manufacturer. It helps in process planning. All the dimensions are in millimeters as shown in Figure 16.

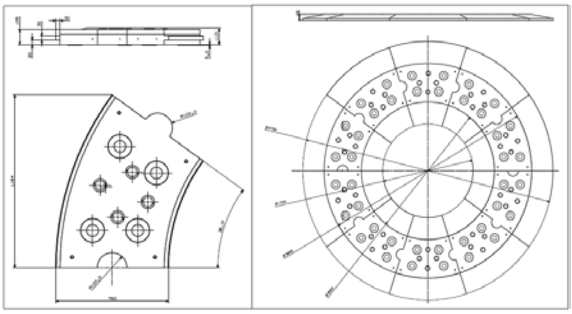


Fig. 16 Size and Dimensions

12. MODEL MAKING

After finalization of the concept and design, model making started as per the detail design. For proof of concept prototype model - wood, putty, water paint and spray paint are used to make the model. For the final concept - thermocol, wood and sticker papers are used to make, mock up model. Details of manufacturing are shown in Figure 17.

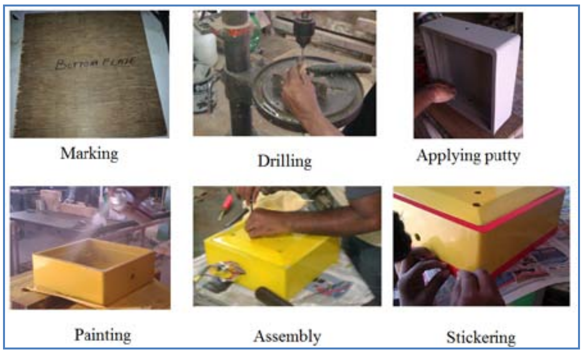


Fig. 17 Model Making – Proof of Concept

For the manufacturing of proof of concept wood material is selected to reduce the material cost. Manufacturing involved different process like, selecting raw material, sizing of the plates, marking, drilling applying putty, painting. Sizing and pocket machining is done by milling process, marking is done with the help of height gage, marker and steel rule, and holes are produced through drilling process. After all the process finished putty applied before the painting is done, because the painting finish depends on the quality of putty surface. Then assembly is done, stickers are applied at the final stage. Thermocol is used to house the LED output. Figure 18 shows the final assembled energy harvesting device with LED output.

Fig. 18 Final Assembly - Proof of Concept

Model Making - Final Concept Mock-up Model

Based on the detailing mock up modelling (1:2 scale) of final concept started. Thermocol material is selected for mock up modelling, because of its light weight and low material cost. Figure 19 shows the different process carried out, it involves thermocol cutting, paper cutting and gluing. The final assembly is stickered with radium stickers of red and yellow colours. As per feedback from user study animal footprints are stickered on the children step area. Figure 20 shows the final outcome of model making.

Fig. 19 Model Making – Final Concept

Fig. 20 Final Concept

13. VALIDATIONS

After manufacturing mock up model, product was validated by checking its features and some of the key functions. Figure 21 shows some of the functions are checked.

Fig. 21 Product Validation

Figure 21 shows the product validation. User feedback collected on the final prototype and mock up model. Users find the appearance of the product is eye catching, animal foot print is a good thought. And the LED output housing uses the sharp pins, so they identified the safety concern (Figure 22).

Fig. 22 User Feedback

14. CONCLUSION AND FUTURE WORK

14.1 Conclusion

By doing literature review it is understood that, what all the research carried out are related to energy harvesting device from human footsteps and scope of improvements. Design research methods like product study, market study, user study and ethnography helped in knowing the existing technology to harvest human footfall energy, who are the competitors. And it's understood that in India, there are no manufacturers of energy generation device from human footfalls. QFD and PDS helped in generating concepts.

Concepts were generated by addressing the issues like safety, ergonomics, simplified mechanism, aesthetics and cost. Model making gave an opportunity to learn model making techniques, manufacturing process and difficulties involved, and, linked the gap between, designer and engineer thoughts.

Mock-up model (ratio 1:2) developed, to understand the features and feasibilities of the product and users feedback found satisfactory. Working prototype developed as a proof of concept to harvest energy from human footfalls. Piezoelectric material discs were used to harvest footfall energy to usable form of electrical energy. Simple rack and spring actuated mechanism used to create vibrations on the Piezo discs. The concept was proven by validating the model by connecting it to LED output of 40 numbers. The prototype is generating 15V and 200mA, this can be stored and use for later applications.

Based on the model making and prototype validation arrived to below mentioned conclusion.

1. By hitting Piezo DC Voltage is obtained
2. It is pulsated DC voltage produced
3. Current produced is of micro amperes
4. One Piezo disc produces 500mv to 1.5V and Current is 10 micro amperes
5. The output of the Piezo disc is completely depends on the efficiency of the mechanism
6. One human footstep generates 10 to 15V and 200 micro amperes of current
7. By using compact step-up transformer, the output can be amplify to different multiplications, it depends on the ratio of the transformer
8. The design is made detachable it helps in handling and maintenance
9. It is easy for assembly and disassembly

The limitation of this project is, this idea is only applicable to heavy density public areas because the energy produced is a function of frequency of piezoelectric material being pressed not by applying load. And due to the more number of footsteps in busy areas piezo discs are prone to wear and tear, so the piezo discs unit needs replacement from time to time.

14.2 Recommendations for future work

1. Proposed idea encompasses further amplification of the piezo output to a greater extent and obtain constant current
2. To adopt improved technology and making it to commercialization
3. Can think of combining solar technology
4. Can implement wireless data output

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