Energy Harvesting Platform

Michael Lin, Kiara Rodriguez, Travis Badall, Sanjay Khemlani

Dept. of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816, USA

***Abstract* — The objective of this project is to design an efficient source of renewable energy that can provide power for multiple uses. This will be implemented using a platform that utilizes two sources of energy, solar and electromechanical. Creating a pathway using these platforms in a high foot traffic area with a high exposure to sunlight will allow for the platform to light up when pressure is applied and for a charging station to be implemented.**

***Index Terms* — Device charging, energy efficient, piezoelectric transducers, photovoltaic cells, voltage regulator, power monitoring, self-sustained.**

I. INTRODUCTION

Electricity has become a necessity in today’s society. There are several ways of producing electricity, such as coal, wind, solar, water, and nuclear. Out of these possibilities, renewable energy such as solar and wind power can be everlasting. Solar power can be harvested to charge batteries which in turn can power other electronics.

Another potentially unlimited energy source is vibrational energy. This type of energy is produced when there are oscillations occurring about an equilibrium point. We can create this type of energy easily with footsteps. By using technology, such as piezoelectricity, that can convert mechanical energy to electrical energy, we can harvest these vibrational energies produced by foot traffic, and turn it into electrical energy that can be used to power energy efficient electronics. One efficient way to do this is to create a floor platform that people can walk on. The pressure produced from the footstep combined with piezoelectric effect can produce a high voltage and low current, which will be enough to power LED lights. This platform will be implemented as sidewalks or pathways in locations with high foot traffic, such as theme parks. The LED lights will be acting as extra entertainment as it lights up when stepped on.

The Energy Harvesting Platform is a hybrid between solar power and piezoelectric power. The solar power acting as the main source, charging the battery and powering the microcontroller that monitors the power output from each of the platforms.

II. OBJECTIVE

Our main objective for this project is to design an efficient source of renewable energy that can provide power for multiple uses. The secondary objectives include managing a low-cost design, high durability of the product regarding different weather conditions, convenient dimensions for the platform to fit in various places, and the sensitivity consisting of how much pressure would be needed to create a voltage. The objective regarding software would involve feedback from the system of productivity and efficiency displayed on an LCD containing information such as how much voltage is being obtained from each tile, the total amount of voltage produced, and the amount of power supplied to use.

III. DESIGN REQUIREMENTS

The requirements of this project consist of providing enough voltage to power a charger for cellphones using solar power. The microcontroller collects and provides data to users. The dimensions of the platform are to be within acceptable range to be placed in various areas. The platform must be durable enough to withstand various weather conditions. The product safety must be approved by government standards. The rechargeable battery should be long lasting to prevent constant replacements. The platform must be placed in a location with an abundance of sunlight and foot traffic. The LED lights should light up within two to five steps, getting more consistent as more foot traffic occurs. The cost and manufacturing of the platform should be low but profitable. The pedestrians walking on the platform should not experience any falling sensation, but just a slight drop as if walking on soft soil.

IV. SAFETY REQUIREMENTS AND CONSTRAINTS

As with any products, the safety of the users and public is important. Constraints are also set to prevent the platform from becoming too expensive or unusable in public areas.

As the platform is renewable energy based, the platform should not produce any waste that would harm the environment or surrounding areas. A safety constraint is that the user should not slip or trip over the platforms. The platform should be affordable, but still profitable for the company.

The product must reliable. Although the battery can only be charged under sunlight, the LED powered by the piezoelectricity will always work while there are people walking over the platforms.

V. PIEZOELECTRIC TRANSDUCERS

The piezoelectric effect generates an electric charge in response to applied pressure on a crystallized material.

Whenever these piezoelectric discs are impacted, bent or otherwise distorted in some way, it disrupts the internal equilibrium and generates electrical energy [1].

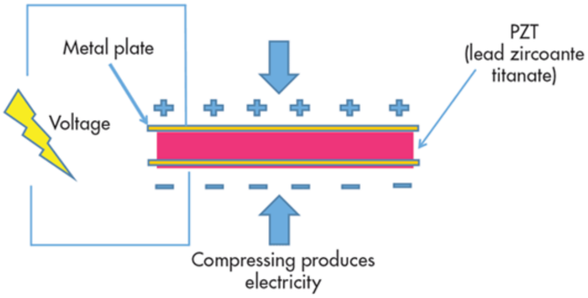

Fig. 1 Piezoelectric Effect

The above figure shows the basics of the piezoelectric effect. The pressure applied to either side of the crystal creates a voltage difference between the two plates and generates very small amount of current

For this design, piezoelectric discs will be placed underneath the platform and pegs connected to the top of the platform will impact the discs when pressure is applied. There are many design considerations when choosing piezoelectric transducers. Possible solutions involve buying a few very high-quality transducers or obtaining many transducers with slightly lower quality for around the same price. The latter option was chosen and two 12 packs were purchased for $25.00 each.

The initial design plan was to have the energy harvested from these piezoelectric discs to power a charging station, but through countless hours of research and experimenting, it was discovered the amount of energy generated would not be sufficient enough to complete this task. Through experimentation, it was discovered each piezoelectric disc can produce upwards to 50V with a current on the order of tens of microamps. Arranging many discs in series produced more voltage, while arranging them in parallel was found to increase the amount of current generated.

However, even with designing the platform to have twenty-four piezoelectric discs in parallel with the hopes of producing enough energy to charge a battery, it proved to be unsuccessful. The current was inconsistent, infrequent, and came in bursts. It was then decided that the piezoelectric transducers will be used to power LEDs just underneath the surface of the platform to provide extra visual appeal to its' users. In order to provide reliable power to the LEDs, the energy generated will be processed through a rectifier as well as a voltage regulator.

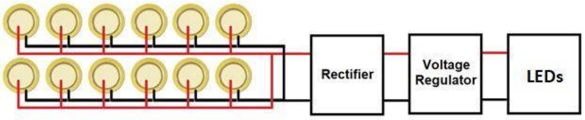

Fig. 2 Piezoelectric Transducer Circuit

The above figure shows half of the piezoelectric transducers that will be connected together, and the circuitry that follows. The initial design was a smaller tile with only twelve transducers, but a bigger tile was chosen for greater efficiency and power output.

A. Rectifier

Rectification is a process where AC power is converted into DC power using a set of diodes that force the current flow in a single direction. When powering digital devices, it is required to supply DC power to them. The initial design involved implementing four Schottky diodes due to its low forward voltage drop, as well as a capacitor to help smooth out the DC voltage [7]. However, in our design, a surface mount integrated circuit was chosen to rectify the output of the piezoelectric discs. The IC chosen has a very low forward voltage drop and boasts 95% efficiency. Once the input voltage is rectified, the next stage in this design to implement a voltage regulator to ensure a constant output voltage that surpasses the threshold voltage for the LEDs.

B. Voltage Regulator

A voltage regulator outputs a constant voltage even if the input voltage is varied or inconsistent. There are few options when it comes to voltage regulator, the main battle being between linear regulators and switching regulators. Linear regulator tends to be very inexpensive and are great for power low powered devices. However, they are not very efficient, with typical efficiencies of 40% or lower. In addition, linear regulators require a minimum voltage to operate due to the voltage drop across the component [5]. One of the biggest advantages of using switching regulators is that it can operated in both, buck mode and boost mode, not just buck mode like in linear regulators. Switching regulators tend to be more efficient but have a downside to having more complex circuitry. Weighing advantages vs disadvantages for both types, switching regulators will ultimately be used in this design.

A buck-boost switching voltage regulator will be implemented so that a constant output voltage is maintained even if the input voltage is higher or lower than the set output. The IC that is utilized in the previous stage for rectification also has a built-in regulator that will be utilized for this design.

C. LEDs

The power generated from the piezoelectric transducers will be used to light up LEDs. The LEDs used are standard red DIP (Duel In-Line Package) LEDs have a forward voltage drop of 2V. The output of the voltage regulator is set to 3.6V to ensure the LEDs turn on without an issue when enough power is supplied to the rectifier and voltage regulator.

VI. SOLAR POWER

The primary source of power for this platform will be from a solar panel just underneath the surface of the platform. The surface will be transparent to allow sunlight to pass through and hit the photovoltaic cells of the panel.

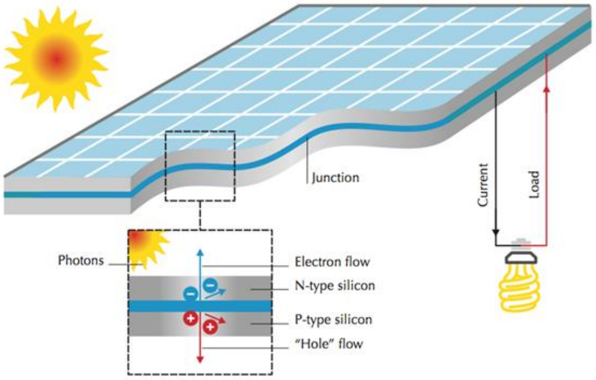

Fig. 3 Photovoltaic Effect

The above figure shows the physics fundamentals behind photovoltaic cells. Sunlight hits the PV cells and knocks electrons loose from the semiconductor material and are captured to produce current.

There are many considerations when choosing a solar panel. Type of material, size, power output, efficiency all play a role. The requirements that were most important for this design was size and power output. The platform will have square dimensions, so it would be ideal if the solar panel as square as possible. The other main requirement is that the solar panel should be able to power everything in the circuit including charging a Li-Ion battery and a cell phone simultaneously.

The solar panel chosen for this design will have a power rating high enough to support a charging system, even on cloudy days. The panel chosen can produce 10W with a maximum voltage and current of 17.5V and 610mA respectively. An integrated circuit that has MPPT capability was considered for this design after consultation with a faculty member, but ultimately was not able to be implemented due to troubleshooting issues and time constraints. A voltage regulator that allows a wide input voltage range will be used instead and should allow the rest the of circuitry run properly, even under non-ideal conditions.

Solar panels produce DC power, however, the voltage needs to be regulated to be a constant output to ensure the battery charges properly and that the pins of the microcontroller avoid any damage.

A. Voltage Regulator

A buck-boost voltage regulator will be implemented after the solar panel to output a constant voltage regardless if the input voltage is higher or lower. This will allow a constant 5V output for input voltages as low as 2.7V (for non-ideal weather conditions) and encompasses voltages up to 40V which surpasses the maximum voltage rating of the solar panel chosen. The voltage regulator will also ensure the correct and stable voltage for the charge controller circuit as well as the microcontroller and LCD display.

B. Charging station

The charging station that is implemented in this design contains a USB port for cell phones as well as an external lithium-ion battery. There are few charge controller options to choose from, such as a shunt charge controller, series charge controller, and others. A shunt charge controller allows current to flow into a battery until it reaches a voltage set point. The voltage set point is determined by the voltage rating of the battery at full charge. When this voltage is reached, current will flow through a shunt transistor to prevent any further current to travel to the battery. A series charge controller utilizes a switching mechanism in series with the input to control the charging of the battery. When the battery reaches its max voltage, the switch opens and causes an open circuit in order to stop the current flow into the battery [9].

Ideally, a MPPT charge controller would be used as it provides the extraction of maximum available power from the photovoltaic cell, but failure to fully integrate with the rest of the design lead to choosing a linear charge controller IC specifically designed to work for the external battery. The external battery will allow a user a charge their phone at night or a very cloudy day. The power rating for the solar panel chosen allows for the external battery as well as the USB port to charge simultaneously during the day.

The charge controller chosen for the charging station is the MCP73833 from Microchip, A development board containing this chip that worked flawlessly in this design will be replicated on the PCB. This IC is specifically designed for lithium-ion batteries and it implements a few precautions to prevent any damage to occur such as preventing reverse current going back into the circuit, overcharging, over temperature, etc. The charging station will also include LED status indicators for power, charging and end-of-charge.

For demonstration purposes, the design includes a stand next to the tile that will have the LCD display, LED status lights, USB charging ports and buttons to cycle back and forth between LCD readings.

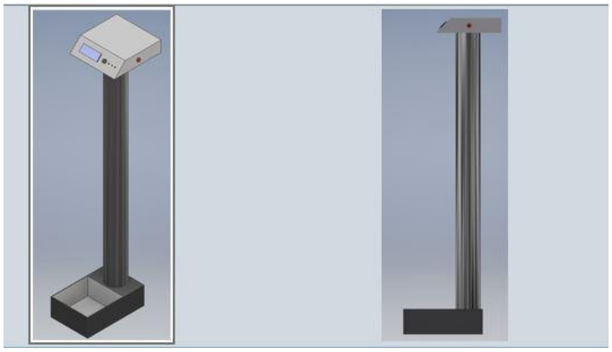

Fig. 4 Charging Station Design (Demo Only)

The above figure shows the design that was created for the charging station for demonstration purposes. If a charging station were to be implemented, it would be a much more discreet and only have USB ports visible to the user.

C. Battery

The rechargeable battery that we use is very important. Although lead-acid batteries are very durable and lower cost, lead-acid batteries have low cycle life and need to be replaced often. Li-Ion batteries are used in this design due to their longevity and ability to fast charge. A 3.7V battery was chosen since that has the same voltage rating as a cell phone battery. As far as capacity goes, a 4400 mAh capacity was chosen because it would be able to fully charge a modern smartphone on its own.

D. Microcontroller/LCD Display

Given one of the main objectives for this project is to be completely self-sustainable, energy from the solar panel will also power the microcontroller and LCD display. The microcontroller will be used for power readings from the piezoelectric transducers, solar panel and battery and will ultimately display the results on the LCD. This will be explained in the following section.

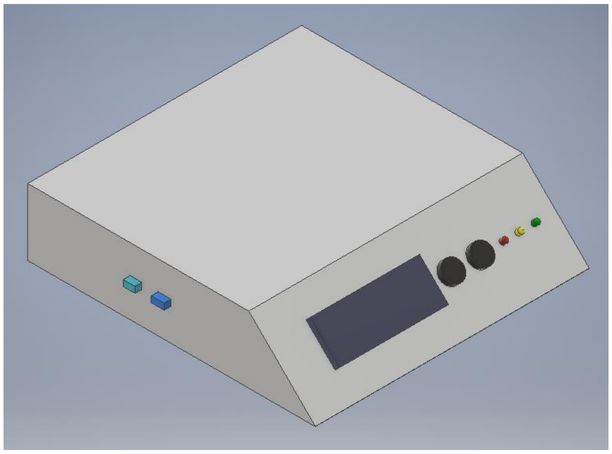

Fig. 5 User Interface Module Left

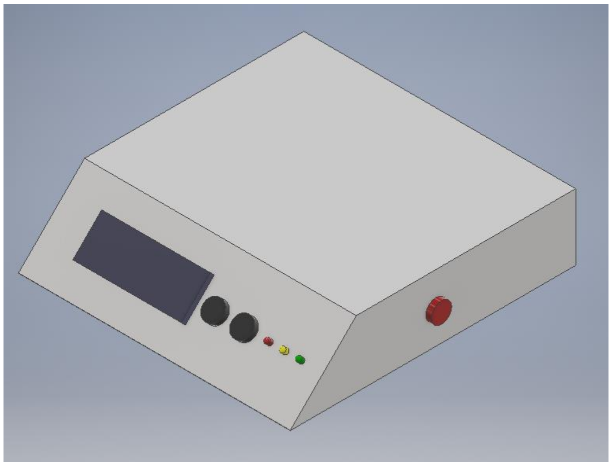

Fig. 6 User Interface Module Right

In the above two figures, on the front of the module are an LCD display, two cycling buttons, and three status LEDs. On the right side, is a reset button and on the left side are two USB ports for charging.

VII. POWER MONITORING SYSTEM

For this project, power monitoring is used to observe and track the platform's performance. This is done through a simple system where a microcontroller is interfaced with DC sensors for measurement collection and the results are displayed through a 20x4 LCD, all for providing the user with a real-time update on source outputs from the platform as well as battery ratings which will be used for charging a small device.

This system measures current and voltage coming from each source and uses these measurements to calculate the power in milliwatts being created by the platform per each source. All this is done through a set design obtained through testing for both hardware and software that worked best with the project.

A. System Hardware

The main component of the power monitoring system is the ATmega328P microcontroller from Atmel. This microcontroller is chosen for its abundant amount of GPIO pins, the built in ADC peripherals and extensive documentation and support which facilitate integration [3]. It also provides for digital communication peripherals, necessary for the implemented system. The microcontroller is integrated with the rest of the system circuit through the Arduino IDE, and its schematic set accordingly with an external 16 MHz clock.

In the earlier stages of designing a power monitoring system, voltage dividers were used with shunt resistors, along with the built in ADC modules present in the microcontroller to collect data and make final calculations. Over time this proved inefficient and taxing as power dissipations in form of heat was constantly experienced. There were also precision errors that caused long term inaccuracies. This lead to the use of the INA219 from Texas Instruments [4], a current/power monitor interfaced with the microcontroller through I^2C bus. For this project three of these modules are used, along with shunt resistors to make the respective measurements.

This module uses high-side sensing to measure bus voltage and load current with a built in ADC which can be configured to 10 or 12-bit, 12-bit as the set configuration for this project. This module also allows for address configuration allowing for the use of multiple components of the like. Overall, these provide for high precision measurement for our needed power calculations, without any of the mentioned drawbacks.

Another important aspect to this design is the character LCD, which provides the real-time data as indicator of the platform's performance. With an abundance of pins and the I^2C serial interface bus currently in use, a 4-bit parallel interface is used to further simplify software integration. This also allows for data to be sent much faster to the display.

B. System Software

The main functionality of the software resides in reading analog signals created by the platform and displaying the power related to those signal through an LCD display. Its secondary function cares for reading and monitoring the battery outputs. This software uses the sensor modules and the LCD through the microcontroller to accomplish power monitoring. Through designing this program a few things were taken into consideration for the implementation to be successful.

A basic understanding of the program is given below in figure 7.

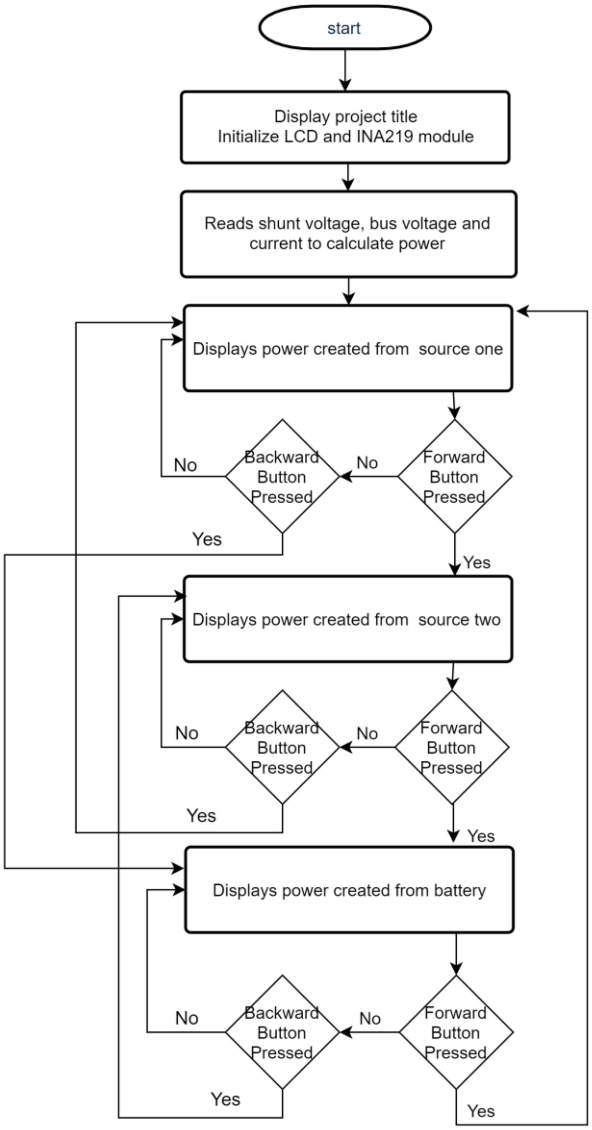

Fig. 7 Power Management Flowchart

Within the software, available libraries are used to condense code, as well as set the correct configurations for the LCD and the sensor modules. The LCD is configured to write to the internal RAM of the LCD and thus display data. It is also configured with the minimum 4-bit parallel setting, where the last four data pins are configured to specific data lines. The contrast of the LCD is also done with the pulse width modulator available in the microcontroller, which eliminates the need for a potentiometer. Through the code, this can be adjusted to any voltage powering the LED in the display.

Given the design utilizes three sensors, the serial bus address is configured to establish three different 7-bit slave addresses per each module. The main function of the program is controlled by a single loop to endlessly collect data, instantaneously and seamlessly. Given this, different delays are set throughout to control how data is displayed as well as the duration of measurement sampling. Data sampling is done every five seconds to allow for sufficient display time between power collection from the source.

Data collection is done by measuring the shunt and bus voltage, as well as configuring the current register and shunt resistor register to read the analog value and use it to calculate power. Shunt and bus voltage are used to obtain the load voltage and thus power is calculated with the current and load voltage from the source. These are seen in equations (1) and (2) respectively,

$$V_{load} = V_{bus} + V_{shunt} \quad (1)$$

$$P_{source} = I \times V_{load}. \quad (2)$$

Another important feature is display cycling between data. This is essential as the used LCD is relatively small and can't display all source data at once. This is easily remedied with the use of buttons to cycle between each display screen. For convenience forward and backward buttons are added to provide ease of use. A custom delay is set to provide for quick, but not immediate response to the button state.

Lastly the battery is also monitored to display the voltage, current and power, thus observing the fluctuations when the battery is charging from the sources and discharging from both self-discharge and discharge from charging the electronic device.

VIII. SYSTEM HOUSING

The platform is designed to be placed at places with human traffic and could be placed out on the road. The design of the housing needed to be able to withstand constant pressure as well as the weather. As it is placed in the ground, the housing must be able to prevent water from leaking in and damaging the electronics inside. The material chosen to build the platform has an impact on its performance. Ideally, the platform would be made with high resistance materials such as vinyl tiles or white cedar wood. However, with the group's budgeting, birch wood was selected. Compared to vinyl materials or white cedar, birch wood is cheap, light, and easy to laser cut to the design specifications and perfect for the prototype of the platform. As the platform will be outdoors in order to harvest solar energy, the platform will require weatherproofing. This problem can be solved by covering the exterior with weatherproof sealant such as epoxy.

The housing of the platform is designed to allow pressure to be put on piezoelectric transducers. When the platform is stepped on, the springs on the corners of the platform will compress, lowering the rods, and applying pressure to the piezoelectric transducers, generating power. Once the user steps off the platform, the springs will push the top of the platform back up, releasing the pressure from the transducers, returning to standby position for the second step. Shown below is the side view of the platform.

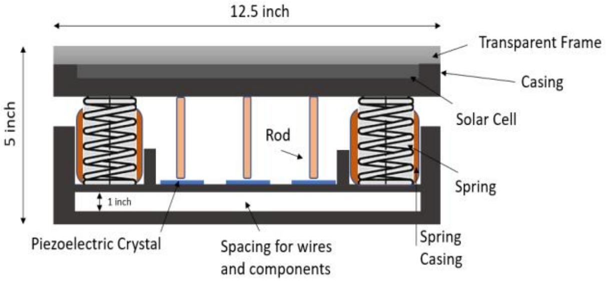

Fig. 8 Platform Internal Side View

As shown in the diagram, the spring casing will act as a physical stop and prevent the rods from exerting too much force on the transducers. This allows the platform to only compress by about 2 millimeters, which is noticeable by the user, but not enough to cause the user to slip or fall.

The acrylic frame placed at the top of the platform allows sunlight to pass through to the solar panel. The frame also acts as protection to prevent the solar panel from being damaged by the footsteps.

There is a spacing set for the printed circuit board, components, and wiring. The picture shown above only displays a single platform. As the design is to have eight or more platforms aligned to create a sidewalk or parts of a pathway, the wiring will lead out of each platform and connect into a central hub, where the battery will be located.

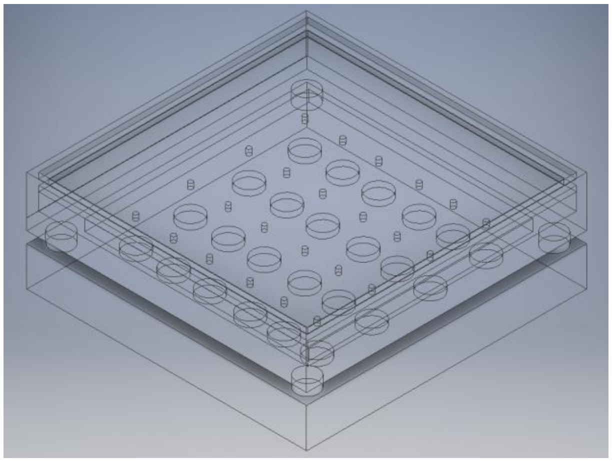

Fig. 9 Platform Wireframe View

Shown above, the piezoelectric transducer disks will be placed within the platform in the disks. 3D printed rods will be placed directly above each of the piezoelectric transducers and secured with screws. The solar panel will be placed within the top layer, covering the screws and the inside of the top layer. Just enough space will allow the LED lights to shine through when the platform is stepped on. LEDs are placed hidden between the solar panel and the acrylic sheets.

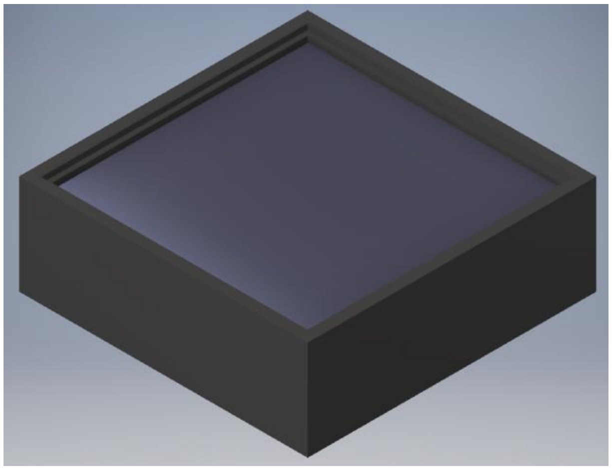

Fig. 10 Diagonal View of Final Platform

The above figure is the rendered picture of the completed platform. The platform will be covered, the only thing visible will be the solar panel and the lit-up LED lights when the platform is stepped on. The complete pathway will consist of eight or more of these platforms for maximum efficiency and energy production.

IX. CONCLUSION

The Energy Harvesting platform consists of harvesting and storing solar energy, converting mechanical energy to electrical energy, charging circuits, microcontroller units, LED lighting, power regulation systems, LCD displays, data gathering, and printed circuit board fabrication. Each member of the group has put in a lot of hours of research, development, and testing to make this project a reality. In the duration of this project, we have learned to perform extensive research, writing technical papers, as well as circuit design and testing.

This project has shown us our current abilities and all the technical skills that we have learned throughout our time in the university. While this project had been challenging, each of the members were able to gain useful experiences that helped us grow as engineers. It honed multiple useful skills, such as time management, research, problem solving, teamwork, preparing and giving presentations, and troubleshooting. All these skills are invaluable to prepare us for careers in the engineering field.

ACKNOWLEDGEMENTS

The authors are grateful for the assistance, support and reassurance of Dr. Samuel Richie and Dr. Lei Wei. Thanks to Dr. Jeffrey Kauffman for his time and his knowledge on piezoelectric energy harvesting. Special thanks to Dr. Reza Abdolvand for all his time, support and suggestions on piezoelectric material that allowed for a successful completion of this project. We would also like to acknowledge systems engineer Douglas Maukonen, and colleagues Clayton White and Chase Cox for their time and support. David Douglas for supplying us with the tools necessary for circuit testing with the oscilloscopes and power generators. Texas Instruments, Linear Technology, and Microchip Technology for providing us with complimentary samples of the ICs necessary to make the project possible.

BIOGRAPHIES

Sanjay Khemlani, is currently a senior at the University of Central Florida and will graduate with a Bachelor of Science in Electrical Engineering in December 2017. Plans to pursue his Master’s degree in Avionics. Currently works for the Florida Space Institute’s Center for Microgravity Research as a Systems Engineer Intern.

Michael Lin, currently a senior student in the electrical engineering department at the University of Central Florida pursuing a Bachelor’s degree. He will graduate in Fall of 2017 and plans to pursue a career in Robotics or related field. He is a student member of IEEE.

Kiara M Rodriguez, is currently a senior in the electrical engineering department pursuing a Bachelor’s in Electrical Engineering at the University of Central Florida and will graduate fall of 2017. Plans on pursuing a career in Software Systems and Integrated Circuits Research and Development.

Travis Badall, is currently a senior at the University of Central Florida pursuing a Bachelor’s in Electrical Engineering. Plans on pursuing a career in power systems after graduation.

REFERENCES

[1] Carmen Emily Yang | Sep 16, 2016, “What is the Piezoelectric Effect?,” Electronic Design, 07-Mar-2017. [Online]. Available: http://www.electronicdesign.com/power/what-piezoelectric-effect.

[2] “What is PZT? | PZT Ceramic | PZT Theory and Use Information”. [Online]. Available: https://www.americanpiezo.com/piezo-theory/pzt.html.

[3] Microchip Industries, “8-bit AVR Microcontrollers”, 2016. Available: http://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-42735-8-bit-AVR-Microcontroller-ATmega328-328P_Datasheet.pdf.

[4] Texas Instruments, “INA219 Zerø-Drift, Bidirectional Current/Power Monitor With I2C Interface”, 2008. Available: http://www.ti.com/lit/ds/symlink/ina219.pdf.

[5] “A beginner's guide to switching regulators,” Dimension Engineering. [Online]. Available: https://www.dimensionengineering.com/info/switching-regulators.

[6] M. Burris, “Learn More About Three Different Types of Voltage Regulators,” Lifewire. [Online]. Available: https://www.lifewire.com/types-of-voltage-regulators-818851.

[7] F. Electronics, “What is a Schottky Diode?,” What is a Schottky diode, Schottky barrier diodes, Schottky diode manufacturers - Future Electronics. [Online]. Available: http://www.futureelectronics.com/en/diodes/schottky-diodes.aspx.

[8] “Shunt Charge Controllers,” Shunt Charge Controllers. [Online]. Available: https://thesolarstore.com/shunt-charge-controllers-c-40_174.html.

[9] “Charge Controllers,” Charge Controllers. [Online]. Available: https://energypedia.info/wiki/Charge_Controllers#Shunt-Linear_Design.