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Design a Micro-wind and Solar Energy Harvesting System for a Wireless Sensor Node to Operate in Coastal and Marine Area as a Senior Design Project

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Design a solar-wind energy harvesting system for a wireless sensor node to operate in costal and marine are as a senior design project

1. Introduction, Project Rationale

The engineering, science, and technology fields, at present, are very dynamic due to continuous advances in computer technology, microelectronics, control and simulation and design tools, helping us to solve traditional and novel problems. Engineering and technology graduates must have a comprehensive background covering a wider range of technical subjects, as well as in system analysis, project management and economics. The graduates must be proficient in the use of engineering and scientific equipment and tools, conducting experiments, collecting and analyzing data, and effectively presenting the results[1-7]. The graduates must also be well-trained in theory, experimentation and testing. If our students are going to successfully function as professional engineers in the international corporate world of the 21st century, they must be equipped to be global engineers who are technically versatile, able to solve problems from systems-level perspective, effective communicators, function in diverse teams and demonstrate social responsibility. Equipping engineering students with the skills and knowledge required to be successful in the 21st century must be one of our primary objectives. Enabling students to practice self-directed learning, creative, to find solutions to design problems that are sustainable are just of few of our educational goals. Projects and project-based learning provide the contextual environment, making learning exciting and relevant to our time, providing opportunities for students to explore real-world problems from a system-level perspective and to develop an appreciation for the inter-connectedness of engineering principles, in which principles and system requirements must be optimized to reach desired system performances[7-10]. Senior design courses fill a critically important role in the engineering curriculum, forming a bridge between academia and industry. These courses bring to the forefront many of the ABET outcomes such as lifelong learning, design, teamwork, problem solving and contemporary issues[8-10]. The inclusion of renewable energy projects, in our senior design course sequence was considered very favorable by many students. Such projects provide multidisciplinary collaboration, valuable hands-on experience, and a working demonstration of green energy systems[5-7]. Our senior design projects are also intended to provide students with solid background in the renewable energy, power electronics, control, and measurement topics to familiarize them with this increasingly relevant technology and relevant applications. Another intended outcome, in place is that the start-to-finish project design is an important issue for engineering graduates to learn, coupled with the requirement of team-work, often multidisciplinary ones, the design experience aligns very well with ABET requirements.

Wireless sensor networks (WSNs) have experienced a fast development, improved design, technology, and extended applications since their appearance for military uses about three decades ago[11--13]. WSN research has grown substantially in recent years, while their applications ranges from traffic, environment, building, industrial process, or patient monitoring to target tracking, and from energy management to health control. The monitoring of physical parameters in natural habitats is an important and critical WSN application for assessing the risks on such ecosystems or to evaluate the environmental impacts of human activities, natural hazards or extreme weather. Rivers, coastlines and shores in front of heavy populated areas are such systems of high research and economic interests. Coastal marine areas are becoming very important for economic and social viewpoints as more people and business are located or relocated in such areas. Such areas are particularly vulnerable to the effects of the human activity, industrial, tourist and urban developments, as well as to extreme weather or marine hazards. However, the advances in the information, microelectronics, renewable energy and communication technologies offer solutions for monitoring of such ecosystems in real time and on extended spatio-temporal scales. WSNs are an attractive for river, marine or costal monitoring, because they are easy to deploy, operate and dismantle and are quite inexpensive. Such sensory systems, allowing us to scan and monitor an environment state are a research area in continuous evolution, having also a great potential in engineering education, offering powerful opportunities for multi-disciplinary STEM education. During a project, students need to understand the project objectives, to have mechanisms for the selection of attractive topics, project focus and scope, effort and cost estimation, and to learn best design practices[6-8]. It is worth to remember, that an engineer is a problem solver - designing large or not so systems, operating engineering systems like communication services, power systems, or managing systems and services. Therefore, an engineer should be a designer, a thinker, and a systems integrator. Hence, the education should inculcate into students various aspects such as engineering principles, standards and practices, design methods, modeling and optimization skills, systems analysis, integration techniques and new technologies. An engineer can become a thinker or an innovator only if he or she is allowed to independently put together all applied science concepts to solve a practical problem, by considering every alternative and approach. Lectures, tutorials and laboratories allow students to acquire engineering knowledge, while the project can give them the opportunity to become a problem solver or an innovator. Projects provide several opportunities to the students to learn aspects that are difficult to be taught in a class room or laboratory. This paper documents the experience of developing, testing and deploying an WSN energy harvesting system, highlighting and discussing the students' efforts. This project was developed and completed by a group of four students, during Spring 2017 and Fall 2017 semesters, as their senior project design.

2. Senior Design Project and Project Goals and Objectives

In the environmentally-based energy harvesting systems the main design objective is to develop and implement a unit, providing power to a load long enough and with minimum maintenance. There are many energy sources that can be employed in such systems, such as: solar, hydro, electromagnetic, electrostatic, thermal, vibration, or human body motion. Thus, advanced technical methods should be developed to increase the system capabilities in harvesting energy from all available energy resources and converting them into electrical energy. These developments have sparked the interest in engineering education to include energy harvesting projects into senior design and various engineering courses. Nowadays, there is an increasing interest to harvest energy at a very small scale, for applications such as the ones found in many embedded systems where the power requirements are small (even less than 100 mW). Sustaining the power requirements for wireless or portable devices is an important research topic. However, not all the time the power source design is keeping up with the microprocessors, memory storage, sensors and wireless technology power requirements. For example, in wireless sensor networks, battery-powered nodes are expected to last for a longer period of time, while conducting the battery maintenance for a large-scale wireless sensor network consisting of hundreds or thousands of sensor nodes is very expensive, difficult, if not impossible to perform. Ambient power sources, as a back-up energy source for batteries come into consideration to minimize the maintenance and operation costs. Power scavenging enables the wireless sensor and portable electronic devices to be completely self-sustaining, and even the battery maintenance can eventually be removed or significantly reduced. While the systems continue to become smaller and smaller, yet less energy is available on board, leading to a short runtime for device or battery. Even the researchers continue to develop high-energy density batteries, the amount of energy available in the batteries is not only finite but also low, limiting the system lifetime. Extended life is very important or even critical for systems with limited accessibility, such as those used in monitoring a process in a hazardous environment, or the ones deployed to monitor in harsh, or not easy to access environments[12-18]. The critical long-term solutions should be independent of the limited stored energy available during the functioning or operating of such devices and systems.

This project was designed and implemented by a team of four senior from pour electrical engineering program, it involves finding the best design solution, system testing, optimization and finally the implementation of the system. Two students in the team have strong mechanical background, while one of the team members is a full time power engineer and part-time student. Our two-semester senior design course focuses on planning, development, and implementation of an engineering project, which includes two formal reports, project documentation, two oral presentations, and prototype demonstrations. The course goals are to develop the students' ability to manage projects involving system design, test and implementation. In these two courses, the students are expected to effectively manage their time and team efforts to produce a finished and workable prototype at engineering standards and expectations. Progress formal reports, written reports and oral presentations constitute integral components of this course sequence. Before beginning the projects, student teams are provided with adequate training in project formulation, engineering ethics, management and resource analysis, performance goals and team expectations, public presentations of project work, and individual project supervision. The design fundamental elements are: the establishment of the system objectives, synthesis, analysis, construction, testing and evaluation". In our senior design we have placed this definition at the core of our courses. First we focus on objectives and ask the student to write a short project proposal stating these objectives, and the decisive factors to reach the stated goals. Our projects involve elements of structural design, energy resource assessment, electrical, electronics and computer engineering system design. The second phase is conceptualization and laying down how to achieve the stated objectives. At this point the students are encouraged to draw a block diagram of the design. A set of questions are posed to students to further understand this task. These are some of the typical questions:

- What are the inputs to the system and, what are their characteristics and magnitudes?
- Do the inputs require conditioning?
- What is the medium through which inputs are interfaced to the system under consideration?
- Do the inputs dictate to the system to be designed how to behave, or just activates the system?
- What are the load requirements?
- Is it a single output or multi-output system?
- Are there feedback loops in the system?
- Do the loads require separate power supplies?

Once the students compile the answers to these questions, they are directed to perform system analysis, start the design, component selection, purchase and/or fabrication, and finally the prototype building and testing, as well as the overall design improvements or optimization. The energy harvester must reliably and operate autonomously for minimum five years, with no maintenance while capturing enough energy to fully power the wireless sensor node. The node power consumption is in the node main components: sensors, microcontrollers, power convertors and all other electronic devices and circuits used for the node power management and for radio communication. The energy harvester system also needs an energy storage unit to store excess energy, and to power the node in the event that power sources are not producing any or enough energy due to the weather conditions or any other unexpected reasons. The system must be mechanical resistant to the outdoor elements, wildlife, weather impacts and other affecting or damaging treats[12-14]. As an ultra-low-power circuit, conventional limited operation life batteries used to power such systems are desirable to be replaced with smaller-size and longer life candidates. In this sense, energy harvesters hold great advantages such as almost unlimited lifetime, and no need for recharging or maintenance.

3. Design Approach, Constrains and Solution, System Block Diagram

Project sensing block includes five sensors, air temperature and pressure, humidity, solar radiation and wind speed. The two microcontrollers used here are designed to match the sensor output to the data transmitter-receiver unit, and eventually to provide small size data storage memories. Commercial transceivers are used for wireless communications, are usually transmitting in the free-licensed ISM band and use proprietary of standard (IEEE802.15.4) protocols. Power must be provided to different stages (sensing, data processing, data storage and wireless communication), and for the power conditioning and management units. Transceivers are one of the most power consuming parts of a wireless node. When the transceiver is in active mode, it requires power of orders of magnitude higher than when it is in inactive/sleep mode[15-18]. However, power requirements can also be dominated by the node sensing stage. Low-power sensors and electronic interfaces are critical in the power consumption reduction. The team decided to use solar and wind energy as power sources because of good energy density and availability in the Gulf areas or Southern States aquatic areas. Two lithium phosphate batteries are used as energy storage unit, even are an expensive choice because of their long life operation period, about ten years or more without any maintenance. A maximum power point tracking (MPPT) controller and the battery protection circuit allow the solar PV modules and Micro-wind turbine to charge and protect the batteries, as well as to regulate and control the system energy flow and usage. For the attachment method the team decided to clamp the node a platform through a versatile subsystem. Wires run from the panel back under the bridge where the end node and the battery stack are located inside the enclosure. Wind load, fatigue, and stress calculations were performed to ensure the attachment was rugged enough to last over 5 years.

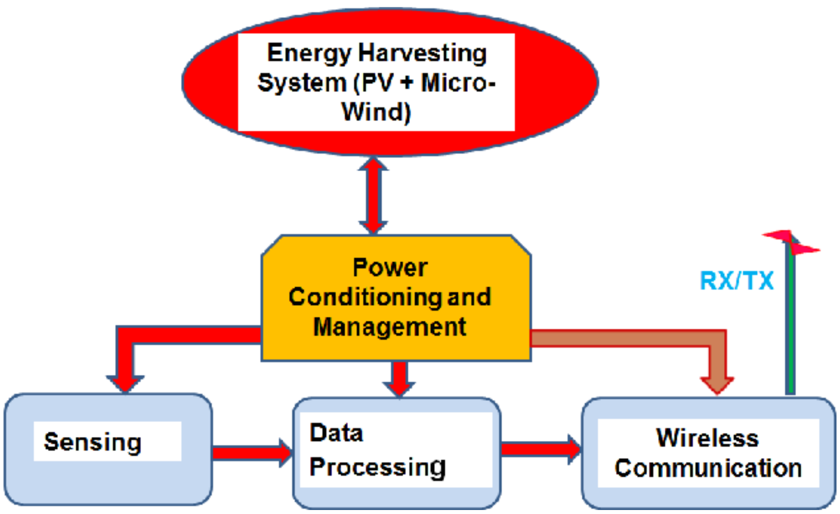


Figure 1: Wireless sensor node block diagram

Average power consumption (Paverage) of a wireless sensor node is given by[16,17]:

$$P_{average} = DP_{active} + \left(1 - D\right) P_{sleep} \tag{1}$$

Here $D = t_{active}/T$ is the duty cycle, when the sensor node is operating, P_{active} and P_{sleep} are the power used by the WSN in active and passive mode, respectively, T is the operation period. One way the lower *Paverage* is by reducing the duty cycle. The power supply subsystem must be able to provide both the total energy demanded during the expected node lifetime and the instant (higher level) power when the node is in active operation time. Figure 1 shows the block diagram of a sensor node. Load accounts for sensing, processing and communication. Conversion efficiency of the system is defined as follows:

$$\eta = \frac{P_{Transferred}}{P_{MPP}} \tag{2}$$

Where P_{MPP} is the power at the maximum power point (*MPP*), collected by the energy harvesting units and $P_{Transferred}$ is the average power transferred to the energy buffer, battery. When the super-capacitors are used, as is the proposed system, $P_{Transferred}$ is computed as the value needed to increase the energy level from E(t – T) to E(t) during a given period T. Only the energy harvesting system that operates on the correct MPP set achieve efficiencies of 90% or higher, and the losses are only caused by the power dissipation by the system components.

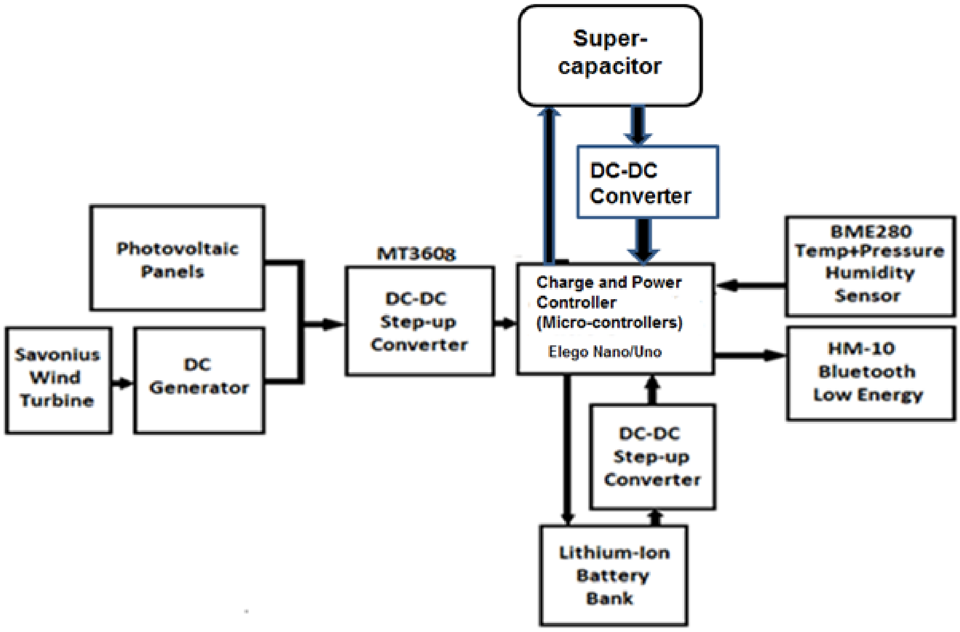
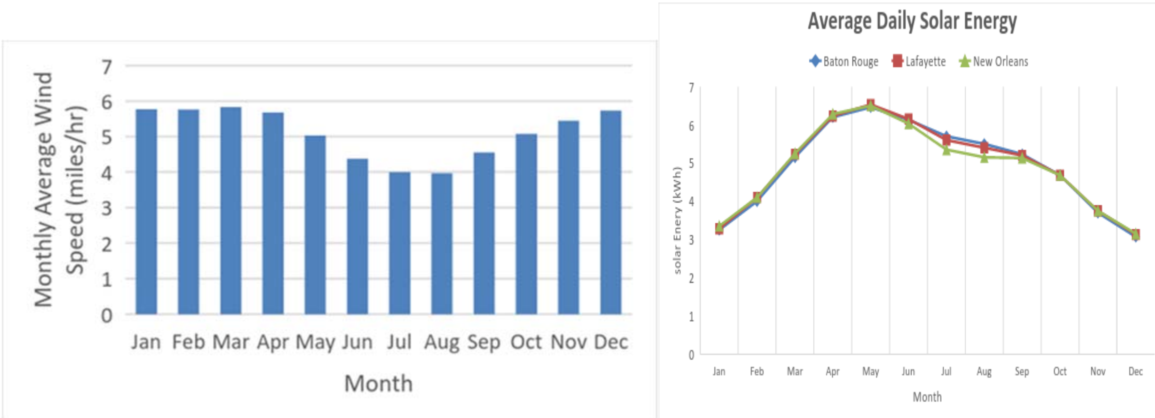


Figure 2 Block diagram of the WSN energy harvesting system.

The block diagram of the energy harvester is shown in Figure 2, the energy being harvested by two PV modules and a Savonius micro-wind turbine, a MT3608 DC-Dc converter steps up the voltage to 7.5V to power the Elegoo Nano and Uno ICs. The powered Elegoo Nano acts as a charge controller by using a relay to switch between charging the battery and dumping excess energy. Meanwhile, the Elegoo Uno is controlling the WSN by collecting information from the ME280 and transmitting it through the HM-10. Savonius rotor is constructed using a Fortus 380MC 3D printer, Fusion 360, a CAD based program is used to design the rotor blade. Figure 5 shows a 3-D rotor blade design. The material used was ABS-M30, because it is 25% to 70% stronger than standard ABS. ABS-M30 also has greater tensile, impact and flexural strength than standard ABS. The layer bonding strength is significantly stronger than that of standard ABS making it a more durable. This allows greater functional tests and higher quality parts for end use. It is an ideal material for modeling, functional prototyping, manufacturing tools and end-use-parts. The rotor blade had to be redesigned a few times to reduce friction. The print time for final fan blade was exactly 2 hours and 54 minutes including warm up and disassembly.

3.1 Resource Assessment, Load Estimates and Component Selection

The critical system design parameters include power consumption by each of the system components, sensors, microcontrollers, DC-DC power converters, power management and control unit, battery protection and charge control subsystem, and the estimate overall system losses. On the other hand, in order to optimum size the system and complain with design requirements in term of the system size, weight, life and operability proper and accurate solar and wind energy assessment in the designation WSN operation areas and regions are also critical and needed in the system design and configuration.



a) **b)**

Figure 3 a) Monthly averages of wind speed; b) daily solar radiation.

Information on the wind resources for the designated locations and areas, where the WSN is panned to operate was required in order to accurate estimate the expected power captured and power output of the micro-wind turbine, and finally to size the wind turbine. The daily, weekly, monthly and multi-annual average wind speeds were compiled and analyzed for several locations to accommodate the Gulf region, centered on Louisiana. The annual average wind speed these areas are ranging from 4m/s to 6.0 m/s, as shown in in Figure 3a. This is a good wind regime, with a potential of providing power to the WSN most of the year. Solar radiation levels typically range from 3700 to 5700 Wh/m^2/day. The solar radiation data was obtained from the National Renewable Energy Laboratory. The daily hourly solar averages (Figure 3b) are taken from NASA's MERRA-2 Modern-Era Retrospective Analysis, combining a variety of wide-area measurements in a state-of-the-art global meteorological model. We have to notice the wind and solar complementarity, wind being higher during the period October-April, while the solar is higher during the April-September. The solar-wind energy complementarity is supporting the system design choice of a combined wind and solar converters for the longer operation life of the WSN.

Figure 4 PV modules

PV Panels: The design uses two of the photovoltaic (PV) solar panel shown in Figure 4.2. Each solar panel is a monocrystalline structure manufactured by ALLPOWERS. The monocrystalline solar structure was selected because it is made from the highest grade of silicon available. Each solar panel is made from a single silicon crystal formed into a bar and cut into wafers. Since the solar cells are made from the same crystal, the electrons are allowed to move freely generating high efficient energy. Therefore, the measured transformation efficiency for these cells is about 18%. The solar cells are encapsulated using epoxies. The panels come with a UV treated surface and a durable weatherproof PCB board. Each solar panel produces a charge of 5V along with a power rating of 2.5W. An average open-circuit voltage of 6.2V and short circuit current of 500mA in sunlight is measured for each panel. The size of each panel measures 130mm by 150mm and weighs 92 grams, are shown in Figure 4.

Savonius Rotor: A Savonius rotor is constructed using a Fortus 380MC 3D printer. Fusion 360, a CAD based program was used to design the rotor blade. Figure 5 is showing the 3D design of the wind rotor blade, and the rotor cross-section diagram. The type of material used was ABS-M30. The ABS-M30 was selected because it is 25% to 70% stronger than standard ABS. ABS-M30 also has greater tensile, impact and flexural strength than standard ABS. The layer bonding strength is significantly stronger than that of standard ABS making it a more durable, allowing greater functional tests and higher quality parts. It is an ideal material for modeling, functional prototyping, and end-use-parts. The blades had to be redesigned a few times to reduce friction.

Figure 5 A CAD drawing of the Savonius rotor blade.

The Savonius rotor uses a 6V micro-gear motor in reverse as a generator for the wind-turbine. The round shaped device has a 3mm diameter long shaft and 2 terminal connectors. The motor has a torque of 30 RPM. The power bank in Figure 5 consists of two Lithium-Ion (li-ion) batteries wired in parallel. Each battery has a charging capacity of 2600 mAh and a 3.7 V nominal output voltage. The bank uses the batteries to power the Elegoo Nano that functions as the charge controller for the li-ion batteries. They also power an Elegoo Uno that operates as the brain of the BME280 and HM-10 simultaneously. They are shown in Figure 6. The BME280 is an environmental sensor developed by Adafruit. The sensor detects the environmental temperature, pressure and humidity. The device also tests altitude. The sensor comes equipped with a 3.3V regulator and a level shifting mechanism that allows it run with a 5V operated Elegoo Bluetooth. The HM-10 Bluetooth 4.0 is manufactured from DSD Tech. It is a 4 pin base board that sends information to mobile devices via Bluetooth. The device is a low energy module with an operating voltage range of 3.6V to 6V. An Elegoo Uno R3 Board is the microcontroller being used to control the BME280 sensor and the HM-10 BLE module. It has an operating voltage of 5V with a recommended input voltage range of 7 - 12V but an input voltage limit of 6 – 20V. The board has a total of 14 digital input/output pins, 6 analog pins and 32kB Flash memory capacity. An Elegoo Nano CH340 board was used as the charge controller for the li-ion batteries. It has an operating voltage of 5V with a recommended input voltage of 7 V to 12V with the input voltage limits 6 V to 20V. The board has a total of 14 digital I/O pins, 6 of which 6 provides PWM output, 8 analog input pins and a 32kB Flash memory capacity.

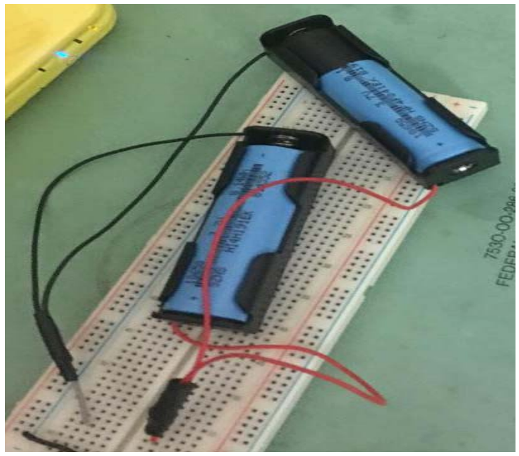


Figure 6 Power battery bank of the WSN system.

4. Mechanical and Electrical Subsystems

The mechanical project aspects focused on three main objectives which includes a system enclosure, side fixtures to support the solar panels and a Savonius rotor. An original enclosure was made to house the project for testing but the group decided to change the design to a smaller size for the final product. The structure needed to be more compatible with enclosed spaces. Therefore, the enclosure underwent several redesigns until the final prototype design was agreed upon. Issues with the enclosure dealt with designing an enclosure capable of supporting the system and being able to fit in enclosed locations. The original design had walls that would've generated an excessive amount of heat. The walls would have also made adjusting electrical components difficult. The final enclosure design lack walls to reduce heat and provide free space to adjust electrical components. The enclosure also contains two 3D printed plates to hold hardware. A generator mound for the motor was printed since the design included pieces that would easily damage even with the thicker filament layers. Solar panels must be placed at an angle of inflexion that receives the most direct sunlight. Therefore, adjustable hinges were implemented on the side fixtures to accommodate the varying degree angles a solar panel may need. The turbine rotor blades went through five alternative designs due increased friction or lack of ability to catch wind. The final design being the biggest turbine met the best requirements for operating use. It has a height of 190mm and a single diameter of 70mm. The total wing span of the fan blade is 140mm.

4.1 Wind Rotor Calculation Basics

The Savonius wind turbine has an elliptical blade that was 3D printed and arranged in a "S". The shape allows a drag force to the basic power driver of the Savonius rotor. The rotor will rotate due to the drag coefficient of the concave surface being larger than the concave surface. Torque will fluctuate during rotations as shown in Figure 7. The actual Savonius wind rotor parameters can be used to calculate the power and torque, as given in relationships 3 and 4. The maximum power output of a wind turbine, sets by the Betz limit is about 0.59 of the input wind-stream power. However the actual power coefficient of a Savonius rotor is 0.18.

$$P = 0.5C_P \cdot \rho \cdot A \cdot v^3 \cong 0.18 \cdot \rho \cdot D \cdot h \cdot v^3 \quad (W) \qquad (3)$$

Here, D is the rotor diameter of rotor *(m)*, h is the height of the rotor blade (m), v is the wind speed *(m/s),* and ρ is the air density (with the standard value equal to 1.225 kg/m^3. The aerodynamic and mechanical losses reduce the actual power by roughly 35% of the Betz limit in the case of a Savonius rotor. However, regardless the lower power output of a Savonius rotor compared with horizontal axis wind turbine, the team decided to employ such rotor for robustness and no control needed, making it more suitable from the system requirements. In order to select the proper DC generator for micro-wind turbine, beside the power output, efficiency, speed of rotation a rough wind turbine shaft torque estimates are also needed. If the ω (rad/s) is the angular velocity, at the rotor shaft torque is then computed with the well-known relationship:

$$\tau_S = P_S/\omega \quad (Nm) \tag{4}$$

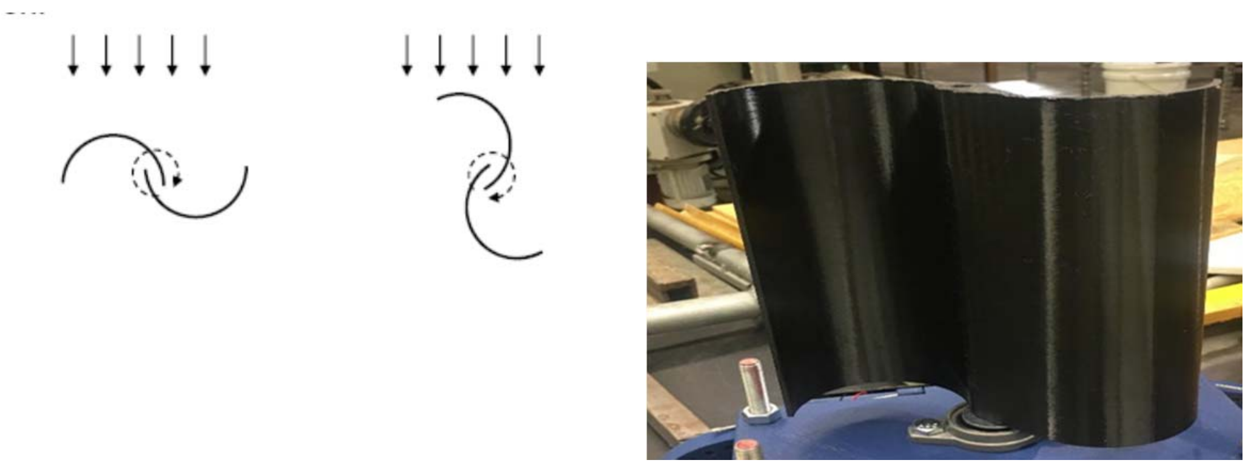


Figure 7 Forces and rotation of a Savonius rotor

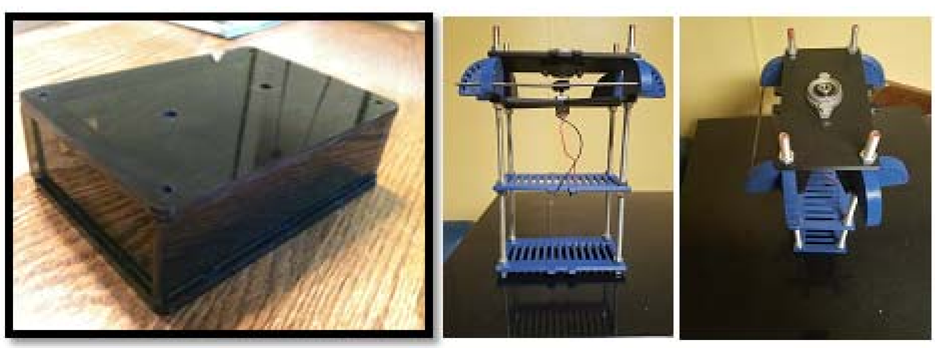


Figure 8. System enclosure picture and anseembydiagrams .

The system enclosure was built to house the system components, including electric and electronic circuitry, devices, sensors, transmitter-receiver unit, energy storage unit, and to support the solar panels and wind turbine. The enclosure must strong enough to withstand the environment where the wireless sensor nodes are deployed. The enclosure was designed and drafted using Auto-Cad software. The enclosure was built, by using an Epilog EXT laser machine. It is made from a 0.150" thick smoked acrylic material that provided to the curtesy of Dontech Inc. (see Figure 6). The enclosure was assembled using socket head screws and stainless steel standoffs provided by McmasterCarr.com. The enclosure the inside-enclusure support systems are shoown in Figure 8, and the PV module support and attachement connectors. Design considerations for the PV module attachment were varied, while allowing for versatility considering the PV panel placement is crucial to maximizing the PV generated energy. The solar panel itself is housed in a waterproof, sealed plastic/acrylic material, that can be easily mounted to the PV module by adjustable brackets to face the optimum Sun direction. To allow slack, the panel leads are lengthened with stranded wire in case the length of wire was to be wound inside the enclosure.

4.2 Electrical Design

The assembled WSN energy harvesting system and its electric diagram are shown in Figure 6. The energy from the PV panels and Savonius wind turbine (WT) is used to power both microcontrollers and the sensor. The PV panels connected in parallel with the micro-Savonius wind turbine can power loads, by initially charging the lithium-ion batteries in order to provide a constant regulated power, as required. However, a MT3608 buck boost DC-DC converter is implemented to step up the provided voltage (from the sources and batteries) due to the low level of the generated power. Therefore, the power stored in the lithium-ion batteries can be used to power the system devices at the required level, even for battery incomplete charged, or lower power levels provided by the PV modules and wind turbine. As a design precaution, the PV panels and WT are switched to a dump load to prevent the battery overcharging. Power provided to the microcontrollers is boosted to 7.5V by the MT3608 DC-DC convertor to accommodate the required input voltage, in the range from 7 V to 12 V. The microcontrollers are programmed in a C/C++ programming language. The Elegoo Nano is programmed to control the duty cycle of power to the devices. For instance, the PV panels and WT is instructed to power the microcontrollers while the batteries are charging. However, when the batteries are fully charged, the microcontroller will turn on a power relay. The relay switches the PV panels and WT to a dump load so that the batteries can now power the microcontrollers. The power stored power in the power bank provides enough voltage to charge the BME280 sensor and HM-10 Bluetooth by providing power to the two microcontrollers. The MT3608 converter was placed on the output of the solar panels and WT to ensure a steady 5.5 V input to surpass the 5V required for the 3.7V Li-ion batteries. Meanwhile, the microcontrollers require 7-12V in the V_{in} pin to power on. Therefore, another MT3608 converter is used to step up the 5.5 V to 7.5 V while the system is charging. Meanwhile, the converter also steps up the 3.7 V from the Li-ion batteries to 7.5 V when the relay switches from the power source to the dump load. The design of the charge controller was changed from its original design due to the inaccurate readings from the microcontroller. This was due to the MT3608 converter originally being wired directly to the batteries. Instead of the read pin being wired to resistor ladder to the common positive terminal; it was wired to directly read the Li-ion batteries' voltage levels at the output terminal. However, the MT3608 was moved to directly boost the output of the power source. Next, another MT3608 was added to boost the voltage levels going directly, through its V_{in} pin to the microcontrollers. The BME280 sensor is used to gather temperature, humidity and pressure information and print it to the serial monitor of the Elegoo Uno. Next, the HM-10 Bluetooth Low Energy module is used to transfer the serial monitor data from the Elegoo Uno to any Bluetooth capable smartphone device. The Bluetooth device was changed directly from Power and Charge Controller Unit to the HM-10 in order to avoid complications in programming and data storage space. Since the HM-10 is a low energy module, it sends out data more efficiently. Instead of continually broadcasting a signal like traditional Bluetooth, it only sends data as requested. This optimizes the WSN's performance on sending and receiving signals from the BME280. In order to connect to the HM-10, a smartphone application is necessary. For this particular WSN the application Bluetooth Console is used.

5. System Implementation and Testing

After each component and part were tested and validate, and after wind turbine, support, enclosure and other parts were manufactured, assembled and tested the prototype was ready for field testing. Figure 9 is showing the energy harvesting system assembled for testing and optimization. The essence of the project and final objectives comprise: finding the optimal working point of each element (source, load, energy storage unit, power conditioning and power management subsystems, sensors and receiving-transmitting unit) with the use of power electronics converters and microcontrollers to manipulate and to control the energy in an efficient and optimum way; the proper use of energy storage elements (Li-In batteries); matching voltages and currents and maximal allowable parameters of the components; and finally the implementation and testing of a complete system. There are numerous possible solutions and it is not the objective of this paper to describe the best solution since such a solution would be based on dynamical models and deep analysis of the components and the use of power electronics and control theory. Since the solar and wind energy sources are available only for limited time periods and are not dispatchable, the students learn to think in terms of available amount of energy and efficient energy conversion, power management, and respectively in terms of optimum usage of energy storage. The use of the energy storage allows using the wireless sensor nodes for a longer time than the availability of energy sources. At the same time use of energy storage units and power management allows the energy use by source start-up or shut-down. The components have their electrical parameters are defined, and it would be advantageous these parameters are not exceeded. A charging and discharging cycle is shown in Figure 10.

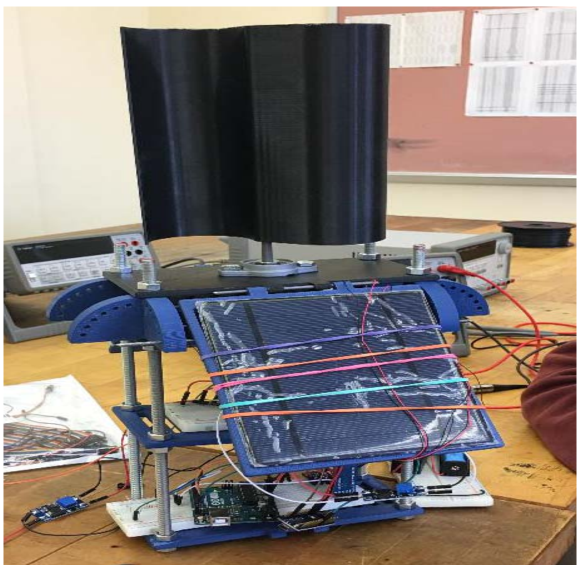


Figure 9: Energy harvesting system for the WSN.

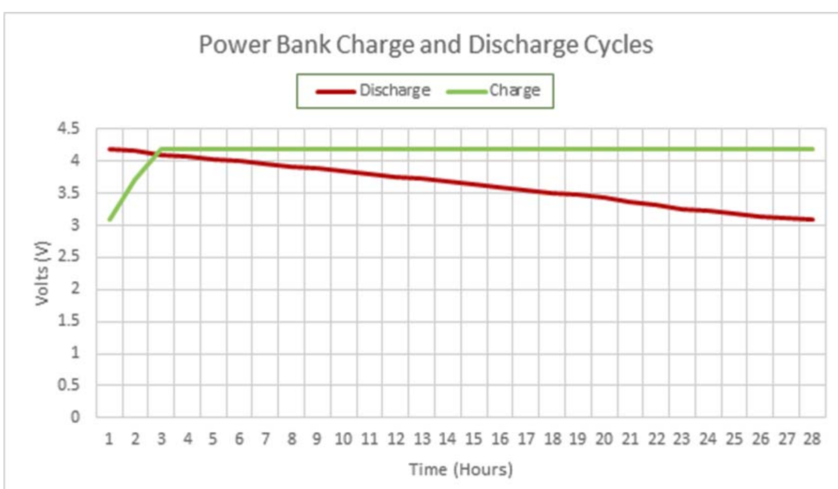


Figure 10. A 24-hour charging-power delivered cycle.

6. Cost Analysis and Project Management

Table 2 Cost analysis

Item	Manufacturer	Quantity	Cost
PV Panels (2)	AllPowers	1	$13.99
*DC Motor	TOOGOO	1	$1.75
Power Bank	AGS	2	$6.99
BME 280 Sensor	Adafruit	1	$17.89
Power Booster	CHENBO	2	$7.19
Bluetooth	DSD Tech	1	$9.99
Microcontroller Mega	Elegoo	1	$10.90
Microcontroller Nano (3)	Elegoo	1	$11.86
3D Filaments	Straysus	1	$175.00
Total			$255.56

The project goal has changed from its original design submitted during the spring semester. The original idea was to design a hybrid power system that provided an adequate amount of reliable electrical energy to a residential dwelling during times of emergency or natural disaster. However, lack of funding has led to a change in direction. During August, 2017 it became clear that the promised financial support for the project had subsided and a new plan of action was necessary. Therefore, the decision to downsize the same power system design to a smaller source of energy for a WSN occurred. The months of September and early October, 2017 were spent researching and collecting the necessary components to build the new project design. Nearly all the necessary components such as the PV panels, sensors, Bluetooth, and microcontrollers were ordered on the www.amazon.com. The rest of the components such as wind turbine blades, and enclosures for the device were 3D printed using a Fortus 380MC which is property of Southern University A&M College. Next, from mid-October to mid-November time was allocated to building a workable prototype of the design and working out design kinks such as adjusting the size of the rotor blade. The last segment of the project was completing the technical report and preparing the presentation. The project has a relatively reasonable expenditure. Overall cost of the project has decreased due to contributions from Southern University A&M College. The university has donated its 3D printer along with the filaments necessary to print the necessary components. As **Table 2** shows the overall price of the project is about $256, while the 3D filaments being the most expensive item at $175.00.

5. Conclusions and Future Work

The goal of the design project is to explore and enhance students understanding of the fundamental engineering principles, power circuit simulation capabilities, sensors and instrumentation and environment monitoring issues, as well as hands- on demonstration of system prototyping. The proposed design solution provides energy from PV modules and micro-wind turbine and backup batteries to power through the power management unit the sensor node. Besides energy efficiency, this new approach guarantees batteries integrity, protection and longer lifetime, while avoiding overvoltage and full discharge degradation issues. Finally, the available energy efficient harvesting system can provide the base for the WSN analysis, testing and quality of service. Future project improvements may include: the inclusion of a low threshold voltage diode for additional system and component protection, and the inclusion of cellular communication components to employ the system in a fully wireless sensor network. In addition a gearbox for coupling the wind turbine with a higher RPM generator that has better performances and generated power, and an inclusion of an Arduino voltage readings in the serial log for better data collection. The project presented above, together with other projects proposed by the authors in the areas of renewable energy, energy harvesting and wireless sensor networks have been used to draw student's interest in the field of renewable energy sources, advanced and intelligent monitoring systems.

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