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A Senior Student Design Project in Marine and Coastal Environment Monitoring

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Abstract

The projects are a valuable component of the science and engineering education. The design experience develops the students' lifelong learning skills, self-evaluations, self-discovery, and peer instruction in the design's creation, critique, and justification. Students learn to understand the manufacturer data sheets, application notes, and technical manuals. The experience, which would be difficult to complete individually, gives the students a sense of satisfaction and the accomplishment that is often lacking in many engineering courses, using traditional teaching approaches. Furthermore, the design experience motivates student learning and develops skills required in industry. The use of computer software packages for simulation and modeling to verify concepts and compare the results, giving the students additional skills necessary in the present day industrial settings. This paper discusses the development of a student project in marine and costal environment monitoring. The project involves a team of final year undergraduate students at our engineering technology program. A simple, low cost wireless sensor network with inherently long operation lifetime, developed based on low cost sensor nodes is proposed in this project. The sensor node is powered by a hybrid solar/PV and micro-wind power system with super-capacitor and batteries as backup units. The proposed sensing platform has the potential to be used as distributed sensing device to deploy in high density to give high spatial and high temporal water quality data, being designed for monitoring a coastal shallow water marine environment, measuring various parameters, such as temperature, humidity, pressure, etc. The sensor node takes the measured atmospheric and oceanographic data and sends them to the sink node using the wireless communication. The description of this system, the system characteristics, performances, the buoy prototype and the user application are presented in details. Various aspects of the educational experience are examined such as the educational goals of the project, project organization, and outcomes. Innovative educational approaches are described such as brainstorming session and discussion with students of high-level choices described by a decision tree, component selections, simulations and system performance and characteristics computation. In the second part of the paper the design solution that was adopted is described in details. The adopted design solution includes: power electronics circuitry (DC-DC converter design and test), maximum power point tracking algorithms, control strategies, battery and super-capacitor selection as energy buffers, and overall system performances. The project is a good example of multi-disciplinary cooperation as well as providing valuable hands-on experimental experience. In addition to providing useful lessons in teamwork, component selection and project management, the project provides a working demonstration of wireless sensor monitoring network and energy harvesting system. 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.

1. Introduction

Monitoring of the marine environment has come to be a field of scientific interest in the last ten years. The instruments used in this work have ranged from small-scale sensor networks to complex observation systems. Among small-scale networks, Wireless Sensor Networks (WSNs) are a highly attractive solution in that they are easy to deploy, operate and dismantle and are relatively inexpensive. The aim of this paper is to identify, appraise, select and synthesize all high quality research evidence relevant to the use of WSNs in oceanographic monitoring. The literature is systematically reviewed to offer an overview of the present state of this field of study and identify the principal resources that have been used to implement networks of this kind. Finally, this article details the challenges and difficulties that have to be overcome if these networks are to be successfully deployed.

The wireless sensor networks (WSNs) is an autonomous network system which consists of large number of micro sensor nodes and has the characteristics of capability of sensing, calculation communication and low cost, and low power. It is a "smart" system that can accomplish varied monitoring tasks, according to different environment conditions. Monitoring of water environment is one of its typical applications. Compared with existing real-time automatic water environment monitoring systems, WSNs-based water environment monitoring system has strongpoint as follows[3, 5-7]: 1) Less effect of the system on ecological environment: nodes transmit water environment parameters to base station by low power and low radiation wireless channel and multi-hop communication protocol. Marine wireless sensor networks offer an unmatched option to a wide range of different domains. The significance of the aforementioned research lies in the fact that it opens the door for a variety of applications as well as new areas of relevant research in wireless networks. The possibility of having hundreds of thousands of sensor nodes diving in the ocean collecting data about the different inhabitants offers a unique opportunity for ocean studies and researchers in the field. The ability to seed wireless sensors that can dive deep in the ocean taking real-time pictures and reporting relevant data about the oceanic life can play a major role in bringing ocean research to new levels. In the following we present the development and designed of a solar energy harvester that can be used to provide power to a WSN for marine environment monitoring system. Coastal marine systems are particularly vulnerable to the effects of human activity attendant on industrial, tourist and urban development. Information and communications technologies offer new solutions for monitoring such ecosystems in real time. Therefore, the last ten years have seen the emergence of various initiatives, from small-scale networks to complex coastal observation systems. Among small-scale networks, WSNs are a highly attractive solution for its easy deployment, operate and dismantle and they are relatively inexpensive.

Energy harvesting or the process of acquiring energy from the surrounding environment has been a continuous human endeavor throughout history, e.g. the use of watermills in ancient Greece, and of sailboats by Phoenicians and Egyptians, circa 4000 B.C. Unlike the conventional electric power generation systems, in energy harvesting concept, fossil fuels are not used and the generation units might be decentralized. There are many sources for harvesting energy. Solar, wind, ocean, hydro, electromagnetic, electrostatic, thermal, vibration, and human body motion are renewable sources of energy. Even the energy of radio frequency waves, propagated due to television and radio broadcasting in the environment, can be harvested. Economic, environmental, and geopolitical constraints on global conventional energy resources started forcing the nation to accelerate energy harvesting from renewable energy sources. Thus, advanced technical methods should be developed to increase the efficiency of devices in harvesting energy from various environmentally friendly resources and converting them into electrical energy. These developments have sparked interest in engineering community as well as the engineering education community to develop more energy harvesting applications and new curriculums for renewable energy and energy harvesting topics. These days there is an increasing interest to harvest energy at a much smaller scale, for applications such as the ones found in many embedded systems the power requirements are often small (less than 100 mW). Today, sustaining the power requirement for autonomous wireless and portable devices is an important issue. However, this progress has not been able to keep up with the development of microprocessors, memory storage, and wireless technology applications. For example, in wireless sensor networks, battery-powered sensors and modules are expected to last for a long period of time. However, conducting battery maintenance for a large-scale network consisting of hundreds or even thousands of sensor nodes may be difficult, if not impossible. Ambient power sources, as a replacement for batteries, come into consideration to minimize the maintenance and the cost of operation. Power scavenging may enable wireless and portable electronic devices to be completely self-sustaining, so that battery maintenance can be eventually removed[18-22]. When compared with energy stored in common storage elements, such as batteries, capacitors, and the like, the environment represents a relatively infinite source of available energy. Systems continue to become smaller, yet less energy is available on board, leading to a short runtime for a device or battery life. Researchers continue to build high-energy density batteries, but the amount of energy available in the batteries is not only finite but also low, which limits the life time of the systems. Extended life of the electronic devices is very important; it also has more advantages in systems with limited accessibility, such as those used in monitoring a machine or an instrument in a manufacturing plant used to organize a chemical process in a hazardous environment. The critical long-term solution should therefore be independent of the limited energy available during the functioning or operating of such devices.

2. Projects in Engineering Education

The engineering, science, and technology field, at present, is very dynamic due to recent advances in computer and other technologies. These advances have resulted in numerous computer programs to solve traditional and novel problems. These programs use the computer's increased computational capabilities and assist in the design, development, and control of complex systems in a matter of minutes. Automation is becoming part and parcel of every industry, and industries need a trained workforce to manage this new development. Engineering and technology graduates must have a comprehensive background covering a wider range of technical subjects. The graduates must be proficient in the use of engineering and scientific equipment, conducting experiments, collecting and analyzing data, and effectively presenting the results[1-4]. This is especially true for the graduates of engineering technology. The graduates must be well-trained in theory as well as in experimentation.

In today's engineering education world in general and in the measurement and instrumentation field, in particular, the main hurdle is the increased cost and complexity of the laboratory equipment and instrumentation per activity station combined with the increased student enrollment on one side, and the budget limitations and space constraints on the other side. The development of computing and information technologies has opened new possibilities for experimental work in instrumentation & measurements[5-7]. Low price of microprocessors, components and computers made possible the realization of remotely accessible laboratories, which can be used for education. These laboratories provide students access via Internet to directly carry out real experiments from remote locations. Interactive experiments are fundamentally different from their batched counterparts. Significant efforts have been expended, during the last decades into organizing off-campus delivery of lessons using multimedia tools. Laboratories based on simulation techniques have also been set-up for remote-access. All these facilities intend to serve the need of increased schedule freedom of both students, faculty and teaching staff. Engineering education has also a costly component that is not directly time-related: sophisticated (and implicitly expensive) equipment, whose use might be difficult because of insufficient availability. Available equipment needs to be shared among researchers and students enrolled in different programs and with different schedules and knowledge levels. Supposing that the experiments are performed in real laboratories and in real time, usually off-line data processing is necessary. This can be accomplished either in the classroom, which supposes a longer student presence in the laboratory and computer set-up of the experimental platform, or in other locations, which means that experimental data have to be delivered somehow to the off-line processing unit, the preferable solution is the use of the Internet layer.

The senor graduating from 4-year ET program must complete some type of capstone design project. It is of utmost that the project selected is not any project, but rather one that simultaneously enhances the learning experience of students, prepares the graduating ones for the real world, increases freshmen retention and strengthens relationships between universities and industries. The key to making the most out of capstone design projects is to carefully select ones that will accomplish all of the above. After completing a 4-year Engineering Technology program, most students are proficient in the principles they studied in the classroom. Whether recent graduates are able to apply these principles to various situations upon entering “the real world” is another story. The capstone senior deign project can be the vehicle to help solving these issues.

ABET defines Engineering Design as: “The process of devising a system, component, or process to meet the desired needs. It is a decision making process, in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet stated objective. Among the fundamental elements of the design process are: the establishment of the objectives and criteria, synthesis, analysis, construction, testing and evaluation”[6]. In our senior design classes we have placed this definition at core of electrical engineering senior design courses. First we focus on the word objectives and criteria and ask the student to write a paragraph stating the objectives, principles, and the decisive factors to reach the stated objectives[7,8]. It is often difficult to provide useful, hands-on practical experience for students as part of their engineering degrees. The projects involved elements of structural design and fabrication, wind and solar energy resource assessment, and electrical, electronics and computer engineering system design and fabrication. First we focus on the word objectives and criteria and ask the student to write a paragraph stating the objectives, principles, and the decisive factors to reach the stated objectives. The second step is conceptualization and laying down the foundation for how to achieve the stated objectives. At this junction the students are encouraged to draw a block diagram showing different components of the system they want to design. A set of questions are posed to students to further understand the task at hand. These are typical questions:

- What are the inputs to 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 system to be designed how to behave, or just activates the system?
- What is, voltage, current and power requirements for the load?
- Is it a single output or multi- output system?
- Are there feedback loops in the system?
- Do the loads require a separate power supplies?

Once the students compile the answers to these questions, they are directed to perform system analysis, design, component purchase and fabrication, building and testing of the prototype, as well as the overall design improvements.

The energy harvester must reliably and autonomously operate for ten years after installation with no maintenance while capturing enough energy to power the communication end node of the sensor network. Though the power consumption of the end node was not fully defined, it was assumed to be the power consumption of its main component: the sensors used to measure atmospheric and marine parameters, such: air pressure, temperature, and humidity, sea temperature, etc. The harvester also needs an energy storage device to store excess energy and use it to power the load when the harvester does not produce power. It must be resistant to the elements, wildlife, and others affecting or damaging treats. As ultra-low-power circuits and micro-systems develop, conventional batteries used for these systems could be replaced with smaller-sized and longer lifetime candidates. In this sense, energy harvesters hold great advantages such as unlimited lifetime, and no need for recharging or power cables.

In this project, students will conduct energy scavenging experiments with a photovoltaic module. The design process can be broke into the following steps:

1. The design and construction of a power electronic circuitry of the harvester;
2. The experimental measurements, data acquisition and analysis; and

The use of an energy harvesting circuitry to charge a battery and a super-capacitor bank

3. Energy Harvesting Systems for Costal Monitoring

This project is an underway project for MET 421/422/423 (Senior Project Design), preformed by a team of four students, two electrical and two mechanical seniors. MET 421/422/423 is a sequence of three-quarter capstone project design courses required for all the BSET majors. The course focuses on planning, development, and implementation of an engineering design project, which includes formal report writing, project documentation, group presentations, and project demonstrations. The goal of these courses is to demonstrate the ability to manage a major project involving the design and implementation of products with a mixture of electrical and mechanical elements as a member of a product development team. In these project-based courses, the students are expected to effectively manage their time and team efforts to produce a finished product in three ten-week quarters. No textbook is required. Progress and formal reports, and oral presentations constitute integral components of this course sequence. Before beginning the projects, student teams are provided adequate training in project formulation and resource analysis, performance goals and team expectations, public presentations of project work, and individual project supervision[9-11].

3.1. Project Description

The team decided to use solar/PV energy source to power the load because of its high energy density and availability. A large lithium phosphate battery provides and two super-capacitors are used as energy storage elements because of their many characteristics that suggest they can operate 10 years without maintenance. Also, a maximum power point tracking (MPPT) charge controller and a battery protection circuit allow the solar panel to charge the battery and to regulate the energy flow in the system. For the attachment method the team decided to clamp to the buoy or a platform used for monitoring. Wires run from the panel back under the bridge where the end node and the battery system are located. Wind load, fatigue, and stress calculations were performed to ensure the attachment was rugged enough to last 5 years. Sensing block include several sensors for temperature, humidity and pressure monitoring. Among processing matches the sensor output to the digital processor, usually, a low-cost microcontroller. Commercial transceivers are used for wireless communications, usually transmitting in the free-licensed ISM band and can use a proprietary of standard (IEEE802.15.4) protocol. Power must be provided to different system stages. Nodes that only relay or receive data can skip functions such as sensing and analog processing. Transceivers are one of the most power consuming parts of a wireless node. The power of a transceiver in active mode is four to five orders of magnitude than in sleep mode[12-14]. The system block diagram is presented in Figure 1.

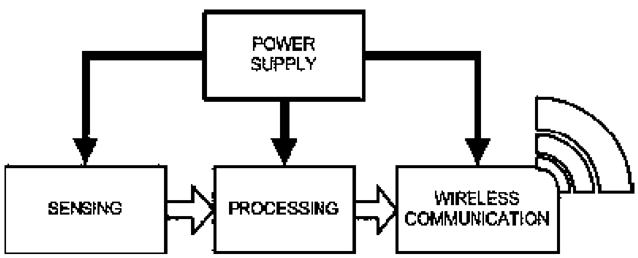

Figure 1. Block diagram of a sensor node

However, power can also be dominated by the sensor stage[14-19]. Low-power sensors and electronic interfaces can help in the reduction of the power consumption of a WSN.

Average power consumption ($P_{average}$) for a wireless sensor node[6] is given by:

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

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 period. One way the lower $P_{average}$ is by reducing the duty cycle. The power supply stage must be able to provide both the total energy demanded during the expected lifetime and the instant power at the active time.

Fig. 2 shows generic block diagram of a sensor node. Load accounts for sensing, processing and communication in Fig.1[12-15]. Conversion efficiency of the system in Fig. 1 is defined as follows:

$$\eta = \frac{P_{Trnasferred}}{P_{MPP}} \qquad (2)$$

Where P_{MPP} is the power at the maximum power point (MPP) and $P_{Transferred}$ is the average power transferred to the energy buffer. When the super-capacitors are used, as is the proposed system, $P_{Transferred}$ is usually computed as the value needed to increase the energy level from $E(t-T)$ to $E(t)$ during a given period T. Only harvester that always operates on the correct MPP can achieve efficiency over 90% and losses are only caused by the power dissipation of the system components. In our case, η has been computed considering the DC-DC converter intrinsic losses.

3.2 System Architecture and Design

Typical design issues for solar harvesters are: the PV module size limiting the maximum power budget; the power consumed by the MPPT and control circuits (usually taking large part of the harvested energy), and the load and the powered systems that could interact with the harvester[19-21]. The harvester architecture, designed after several simulation steps with the proposed model for the PV modules, is shown in Fig. 2. The architecture of the developed harvester consists of three main subsystems: a) the maximum power point tracker sense the light intensity and control the buffer stage forcing the PV module to work in most efficient conditions; b) buffer stage (BS) stores the energy collected form the solar panel into the energy storage devices (super-capacitor and battery); and c) output stage (OS) generates a stable voltage supply for the low-power WSN applications. In the following we introduce the building blocks providing design guidelines and considerations, which help to optimize the performance of the harvester.

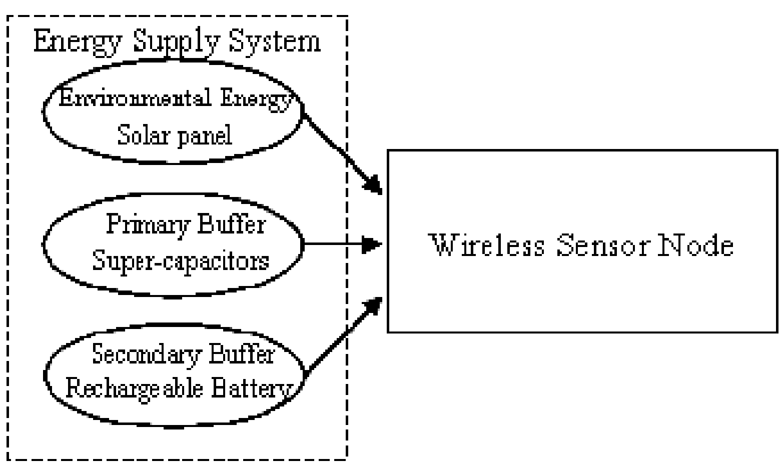

Fig. 2 Block diagram of the proposed system

The MPPT algorithm is designed to automatically find the operating point (V_{PV}, I_{PV}) at which a PV module should operate to obtain the maximum output power under a given temperature and irradiance, following is when the light intensity changes. There are several algorithms to the track the maximum power point (MPP) voltage[14-18]. The most popular ones are Perturb and

Observe (P&O) and Fractional Open-Current Voltage (FOCV)[20,21], which was adopted in this project. The P&O method requires complex control is suitable WSN applications. The short-comings of this method are the high cost and complexity. On the other hand, FOCV is largely used in small-scale and low-power PV applications. This method exploits the nearly linear relationship between PV module operating voltage at MPP V_{MPP} and its open-circuit voltage V_{OC}:

$$V_{MPP} \simeq K_{FOC} \cdot V_{OC} \qquad (3)$$

K_{FOC} is a constant that ranges from 0.71 to 0.78, depending slightly on irradiance conditions[14]. Since the linear factor depends on the characteristics of the solar cell that is being used, it usually has to be computed in advance by empirically or experimentally determining V_{MPP} and V_{OC} for a specific solar cell at different irradiance and temperature levels. However, this is only an approximation and a solar cell rarely operates in its exact MPP, but this MPPT technique is easy and inexpensive to implement and most important does not require a microcontroller, uses lower power to operate. The MPP can be approximated measuring periodically V_{OC} by a temporary disconnection of the PV module from the circuit. The bock diagram of the solar energy harvester is shown in Figure 3, while the physical circuit implementation is shown I n Figure 4.

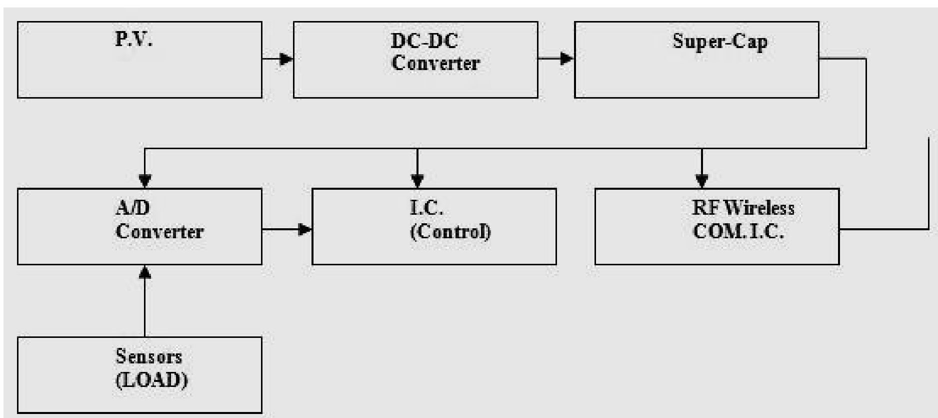

Figure 3 Harvester block diagram

Figure 4 Energy harvesting circuit

The proposed solution uses a super-capacitor from PowerStor that present a very high energy density (100 times that of electrolyte caps) and power density (10 to 100 times that of batteries)[14-16]; equivalent series resistance (ESR) extremely low compared to activated carbon super-capacitors; relative low leak current; ample operating temperature range; and may be recharged hundred thousand times. Considering a duty cycle typical to WSN of 1%, an active node current of 20 mA and a sleeping current of 5μA, the average current is 0.01×20 mA + 0.99×5 μA = 0.205 mA. The sensor node operating voltage is 2.80 V and the super-capacitors will power for 10 hours (estimated period without sun light).Two super-capacitors of 22 F / 2.5V each in series are used in our design, providing the 2.80 V and minimizing the leak current.

Embedded systems, including WSNs contain advanced ICs that require a stable supply voltage to operate correctly and properly. This requirements demand a properly designed output stage with regulated voltage to deliver the power supply to the whole WSN node. A DC-DC regulator combined with a custom enabling and insulation circuits has been selected to maximize the output regulator efficiency. A Buck-Boost converter was selected to give more flexibility in providing a 3.3 V stable voltage with ~ 90% efficiency. Note that efficiency depends also on super-capacitor, battery and the rest of the harvester components. Even with the same irradiance, usually there are significant changes in PV power (P_{PV}) output due to various reasons. The MPPT methods discussed in previous subsections can be used to find the maximum P_{PV} regardless of the irradiance.

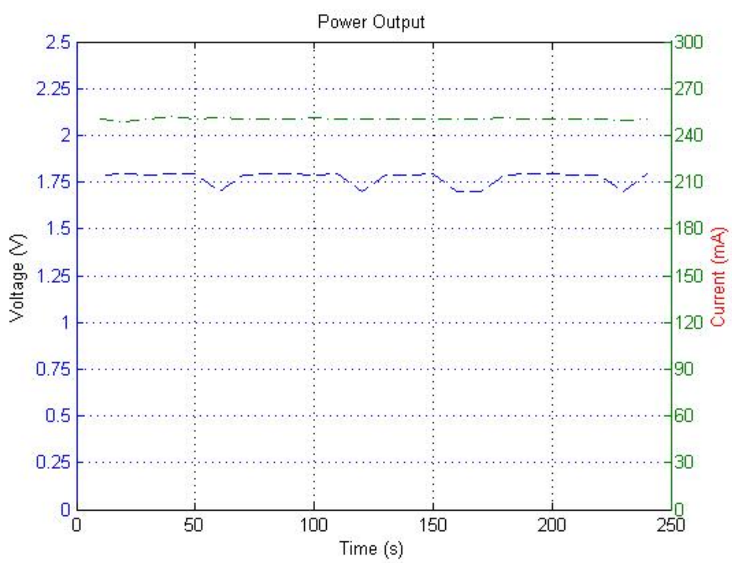

Figure 6 Waveforms showing PV voltage and PV current

The solar energy harvester is targeted to supply low-power WSN devices for marine monitoring under typical environmental conditions. Our scavenger is very flexible and can be attached to commercial sensor nodes which are not designed with energy harvesting features. Circuit consumption and losses vary with the current flowing through the power switches. The solar energy harvester is targeted to supply low-power WSN devices for environment monitoring under typical environmental conditions. He proposed scavenger is very flexible and can be attached to commercial sensor nodes which are not designed with energy harvesting features. Circuit consumption and losses vary with the current flowing through the power switches. In the most constraint conditions (low input power) the total power consumption is under 10μW making this architecture suitable for low power autonomous WSN. The power consumption for wireless sensor device provided by manufacturer with sensors and micro-controller in stand-by conditions is < 1 mW, while the power consumption reaches ~ 50 mW in active mode. Fig. 6 shows the experimental waveforms of the PV module voltage and current, and the output voltage and current for 1000 W/m2 insolation. The PV voltage for both insolation values is kept at around 1.79 V. However, the out power for the second insolation values is only about 60% of the previous one. The power difference is supplied by the storage unit of the harvester.

3.4 Mechanical Design

To adequately collect the ambient solar radiation necessary to facilitate the operation of the WSN monitoring unit, there needs to be a way to modify the direction of the solar panel to compensate for the lack of light at a certain angle or time. The method we found to facilitate the maximum light irradiation of the panel is to mount the unit on a movable ball and socket mount, (see Figure 7). This ball and socket mount was required to be able to be adjusted to any direction in 360º. The design was originally chosen from one of our alternative designs for the solar panel mounting configuration after it was determined that a modular system would be optimal for the generalized applications that our system was to be used in.

Figure 7 Pivoting solar panel mount.

The ball and socket mount chosen is a speaker mount from a high end surround sound system. This specific mount was chosen for its range of motion as well as its mounting capabilities. The base plate is made from thick gauge steel cut from the chassis of an old Macintosh computer, with steel rack stock brazed to the back. This allowed the ball and socket joint to be attached to the base plate. The unit is finished with automotive grade trim around the edges to provide a barrier against the metal and for durability. Because this mount has multiple disconnect points, the ball and socket joint can be taken apart and reattached anywhere the power cord will allow. With the ability to relocate the solar panel assembly to an area off the base unit, we can set the panel in an area that would allow for the best ambient light collection, while monitoring an area that could possibly be multiple feet away from the base station. This configuration would also allow the placement of the base station at a distance closer to another node, facilitating better network communication. If necessary, the solar panel can be mounted on the unit itself, utilizing the two holes on the top of the chassis assembly.

4. Final Remarks and Conclusions

Students learn, verify, and reinforce theoretical concepts by performing experiments in the laboratory sessions and through the project experience. In our approach we adopted the principles of the problem-learning methodology. The design experience develops the students' lifelong learning skills, self-evaluations, self-discovery, and peer instruction in the design's creation, critique, and justification. Students learn to understand the manufacturer data sheets, application notes, and technical manuals. The experience, which would be difficult to complete individually, gives the students a sense of satisfaction and the accomplishment that is often lacking in many engineering courses, using traditional teaching approaches. Furthermore, the design experience motivates student learning and develops skills required in industry.

The development and implementation of a project solar energy harvesting in our senior project design course is described here. The project is used to allow students to apply fundamental engineering concepts as well as principles of engineering design. The societal impact of the project, Solar Energy Scavenging, also makes students more aware of what engineering can do to address current energy issues worldwide. Presently we are modifying the content of the project to address the main concern that many students expressed in their reflection papers, i.e. the level of complexity and the amount of time needed to complete the project. 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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