PIC-Based Solar Energy Harvesting Module Design for Wireless Sensor Networks

Kablosuz Sensör Ağları için PIC-Tabanlı Güneş Enerjisi Tasarruf Modülü Tasarımı

Yazar(lar) (Author(s)): Batur Alp AKGÜL[1], M. Fatih HASOĞLU[2], Bulent HAZNEDAR[3]

[1] ORCID ID: 0000-0002-8332-6764
[2] ORCID ID: 0000-0001-6735-9438
[3] ORCID ID: 0000-0003-0692-9921

PIC-Based Solar Energy Harvesting Module Design for Wireless Sensor Networks

Batur Alp AKGÜL[1*], M. Fatih HASOĞLU[2], Bulent HAZNEDAR[2]

[1]Department of Electronics and Computer Engineering, Institute of Natural Science, Hasan Kalyoncu University, Gaziantep, Turkey
e-mail: baturalpakgul@gmail.com
[2]Department of Computer Engineering, Engineering Faculty, Hasan Kalyoncu University, Gaziantep, Turkey
e-mail: bulent.haznedar@hku.edu.tr, mfatih.hasogu@hku.edu.tr

Abstract

Nowadays, the issue of power consumption is very important in wireless sensor networks (WSNs) and recent developments have allowed solar energy power to be used for WSNs. How to collect and store energy effectively from the environment has been investigated for the WSNs in this paper. Energy consumption issues in the WSNs is the most significant constraints of the wireless sensor node systems. Due to the power limitation, providing electrical power to WSNs often becomes very challenging. Overcome these issues, we have focused on powering up the sensor devices by alternative renewable energy sources such as solar energy along with rechargeable batteries. Also, using different techniques for energy saving is one of the essential tasks in WSNs. Many efforts have been put to reduce the energy consumption of the hardware, software, communication protocols and applications. However, energy consumption still cannot be brought down to the desired level. Therefore, we have presented a renewable-harvesting energy approach for solving the power consumption problem of the WSNs and the utilization of renewable (solar) energy to enhance the lifespan of the WSNs in environmental applications. In this study, we have also proposed a new renewable powered energy harvesting model for the rapid prototyping of any WSN. We have found that these approaches may play a critical role in increasing the lifespan of a WSN.

Kablosuz Sensör Ağları için PIC-Tabanlı Güneş Enerjisi Tasarruf Modülü Tasarımı

Öz

Günümüzde, kablosuz sensör ağlarında (WSN'ler) güç tüketimi konusu çok önemlidir ve son gelişmeler, kablosuz sensör ağları için güneş enerjisi gücünün kullanılmasını sağlamıştır. WSN'ler için güneş enerjisinin verimli bir şekilde nasıl toplanıp depolanacağı bu çalışmada araştırılmıştır. WSN'lerde enerji tüketimi sorunları, kablosuz sensör düğümlerinin en belirgin kısıtlamalarıdır. Güç sınırlamasına bağlı olarak, WSN'lere sürekli olarak elektrik gücü sağlamak çoğu zaman çok zor olmaktadır. Bu sorunların üstesinden gelmek üzere, kablosuz sensör düğümlerini şarj edilebilir pillerle birlikte, güneş enerjisi gibi alternatif-yenilenebilir enerji kaynakları ile güçlendirmeye odaklanılmıştır. Ayrıca, enerji tasarrufu için farklı teknikler kullanılması WSN'lerde önemli işlerden biridir. Donanım, yazılım, iletişim protokolleri ve uygulamaların enerji tüketimini azaltmak üzere birçok çaba sarf edilmiştir. Bununla birlikte, WSN'lerde enerji tüketimi halen istenilen seviyeye düşürülememiştir. Bu nedenle, WSN'lerin güç tüketimi sorununu çözmek için yenilenebilir-hasat enerji yaklaşımı ve çevresel uygulamalarda WSN'lerin ömrünü artırmak için yenilenebilir (güneş enerjisi) enerjinin kullanımı yaklaşımı sunulmuştur. Bu çalışmada ayrıca, herhangi bir WSN'nin hızlı prototipleştirilmesi için yeni bir enerji toplama ve tasarruf etme modeli önerilmiştir. Bu yaklaşımların bir kablosuz sensör ağının ömrünün artırılmasında kritik bir rol oynayabileceği bulunmuştur.

*İletişim yazarı, e-mail: baturalpakgul@gmail.com

1. INTRODUCTION

Advancements in renewable energy sources is increasing the attention in autonomous WSN. Energy harvesting allows long-term operations of wireless nodes, which can extremely reduce the cost of battery charging or replacement. WSNs mostly use battery-powered nodes. Because of limited energy in the battery, energy consumption is a primary factor in the design of WSN, alternate energy sources are essential to permit them to function more effectively and for longer periods of time. Solar cells can be utilized to power the sensor as well as to charge the batteries for WSNs [1], where we aim to cooperate alternative sources to provide autonomy lifetime for WSN. One of the important motivations for this study lies in the exciting opportunity to create a device that relies solely on renewable solar energy and to develop a strategy for managing that energy to extend the lifetime of the WSNs and a rechargeable battery which has a high energy capacity. We have focused on PIC-Based unique power management scheme to coordinate power storage and delivery between a small solar array and rechargeable batteries with a supercapacitor, ensuring long-time operation.

Power consumption of the application are taken into account to select the right hardware for the task and for the maximum energy efficiency in wireless sensor networks, carefully considered the hardware and software partitioning and the trade-offs required to optimize ultra-low power operation. As can be depicted from Figure 1, harvesting is the process of accumulating and utilizing the energy such as solar [2], mechanical [3] and thermal energy [4] present in the surroundings of the device.
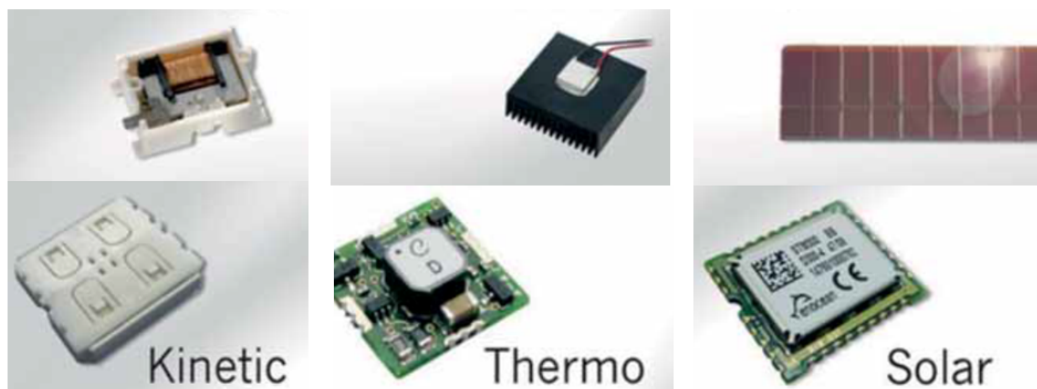
Figure 1. Energy harvesting technologies.

Advanced energy storage solutions, such as renewable energy sources, solar panel, supercapacitors and thin film batteries, have started and combined to apply for new applications with wireless sensor networks. Existing battery-operated systems are benefiting from the application of energy harvesting technology of extending sensor node lifetime. Findings of this work has been compared to the previous studies. The paper is organized as follows; Section 2 presents literature research, Section 3 presents hardware components of the designed sensor node, Section 4 describes the software components of the designed sensor node, Section 5 presents results and discussions and Section 6 concludes the paper.

2. LITERATURE REVIEW

In WSNs, researchers focus on wireless sensing nodes which transfer values without being dependent on wires with sustainable energy. Previous studies on the WSN shows that little attention is directed towards incorporating of renewable energy sources. However, scientists tend to work towards this area has increased recently.

T. Voigt, H. Ritter, J. Schiller [5] utilized solar power in WSN. They have presented two protocols for solar aware routing. Solar-aware routing preferably routes traffic via nodes powered by solar energy. Their simulations of two solar-aware protocols show that significant energy savings can obtained via different scenarios. Results suggested that utilizing solar power in wireless sensor networks is efficient and feasible.

Martino M. and Varley J. [6] developed a Wireless Sensor Node Powered by a PV-Supercapacitor and Rechargeable Battery Trio. Device consists of the WSN with BQ25504-Ultra Low Power Boost Converter with Battery Management for Energy Harvester Application.

A solar based power supply for an agricultural environment monitoring system for agricultural production environment utilizing WSN technology was implemented in [7]. This system contributed to increasing the crop yields and improving quality in the agricultural field by supporting the decision making of crop producers through analysis of the collected information.

Sharma, V., Mukherji, U., Gupta, S. and Joseph, V. [8] studied a sensor node with an energy-harvesting source, and a buffer was used to store the generated energy. The sensor node periodically sensed a random field and generated packets. Only when the energy was available, the packets would be transmitted; otherwise, they were stored and waited upon.

Naveen, K. V. and Manjunath, S., S. [9] developed another low-power solar energy-harvesting system for WSN was employed in an intelligent building. They used several solar cells connected in series and parallel to each other to scavenge energy and utilized a set of ultra-capacitors to store up the energy.

Wu, F. et al. [10] developed a self-powered environmental IoT sensor network system with solar energy. The proposed technique tried to provide an energy solution to keep sensor nodes active and reliable for a whole day.

Vračar, L. et al. [11] developed a Photovoltaic Energy Harvesting Wireless Sensor Node for Telemetry Applications Optimized for Low Illumination Levels. Energy harvesting device intended for use as a wireless sensor network node with non-perpetual operation in the indoor environment.

In the above literature of the WSN studies, it can be seen that power management is not managed by microcontroller. In this study, designed an external PIC based energy harvesting module and power management is fully assigned to microcontroller. All operations of the solar energy harvesting module are managed by the operating system (software) and it has been developed with PIC-C language.

3. METERIALS AND METHODS

In this section, the general information about designing an energy harvesting module and our designed module has been presented in detail. One of the major issues in sensor networks is developing an energy management system to improve the lifetime of the networks.

This section outlines to create a device that uses renewable energy efficiently to extend its network and sensors lifetime. The design, testing, development of a solar panel power unit with a supercapacitor and a battery are presented.

3.1. PIC-Based Energy Harvesting Module Design

Designed voltage module platform uses a unique power management scheme to coordinate power storage and delivery between a small solar array, and rechargeable batteries with a supercapacitor, ensuring long network life operations. Energy consumption data was measured while the system is running and reflects the maximum amount of consumption. When operating at maximum power, power consumption could be high and sensor node's battery life could be shorter. Therefore, efficiently utilizing solar energy harvesting module can maintain a prolonged network lifetime.

### 3.2. Requirements of the PIC-Controlled Voltage Module Design

In this section, requirements of the PIC-Controlled voltage module design with integrated renewable energy for wireless sensor networks are described in detail. Voltage module platform will be performed in the following functions and PIC based voltage module platform must be adhered to the following constraints:

- Collect solar panel voltage, super capacitor voltage, battery voltage.
- Implement a DC/DC Converter to regulate the output voltage of the solar array as dictated,
- Recharge the rechargeable devices with a supercapacitor and solar energy,

- Control power management program to maximize the operational lifetime of the WSN,
- Manage renewable energy (solar) between the rechargeable battery and solar panel energy.
- Recharge the rechargeable devices with surplus solar energy,
- Use a rechargeable battery as an energy storage device,
- Operate outdoors during the day under varying lighting conditions and during the night.
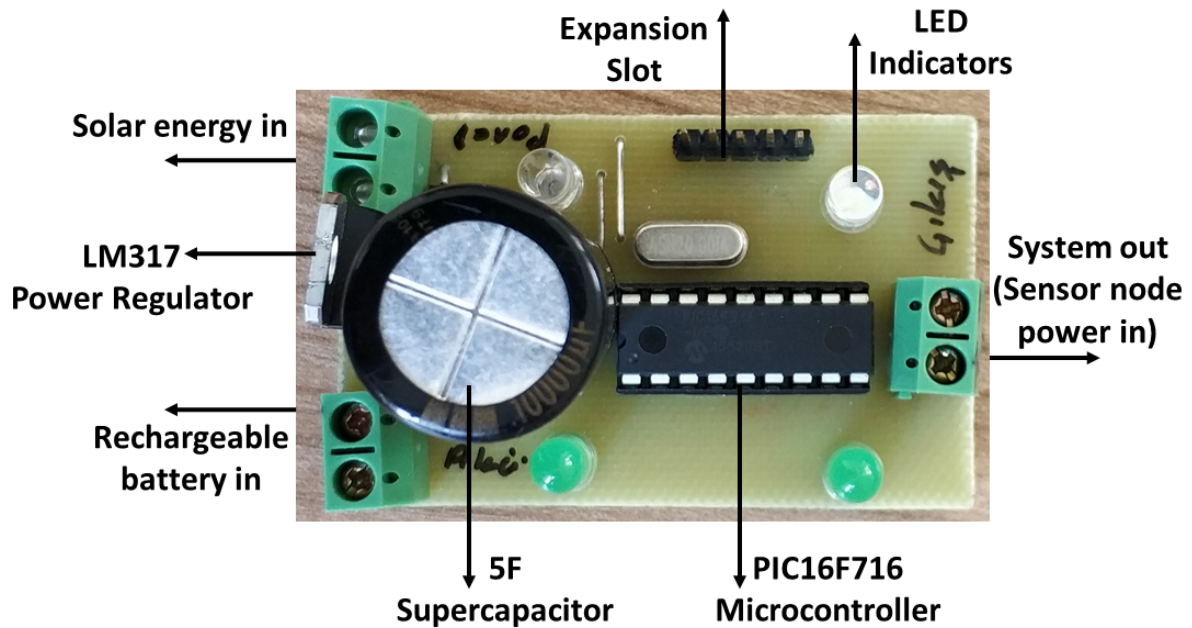
3.3. Architecture of the Designed Solar Energy Harvesting Module

Collecting solar energy from the environment is one of the best solutions to the power depletion problem in sensor nodes participating in a WSN. Solar energy is one of the most common ways of employing ambient energy sources, supporting or replacing battery power supplies. Solar cells are used to convert the sunlight into direct electrical current, using the photovoltaic effect. The diagram of the solar panel energy harvesting system is shown in the Figure 2.
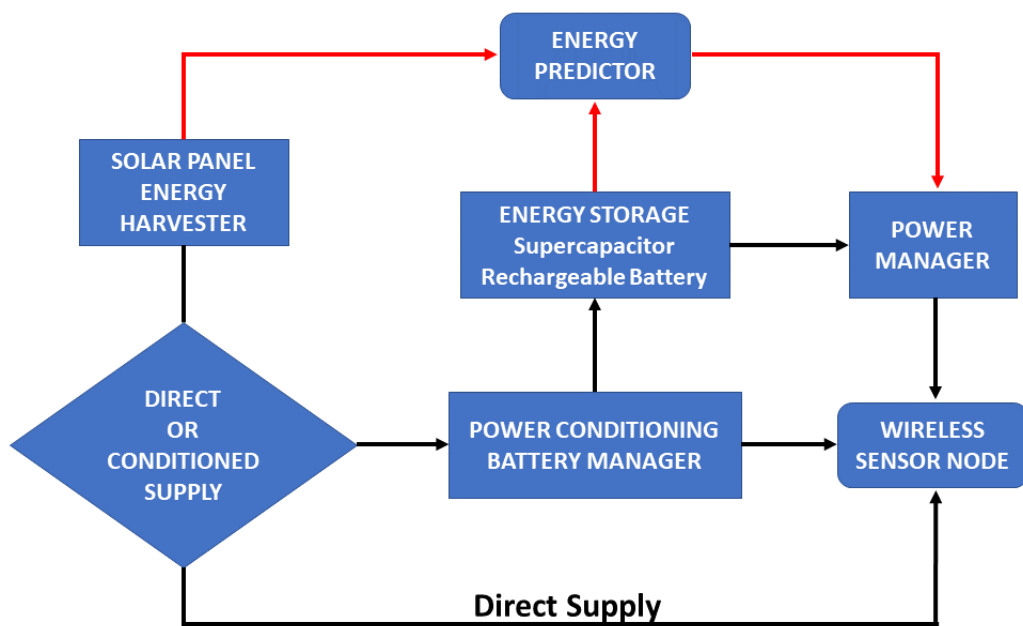
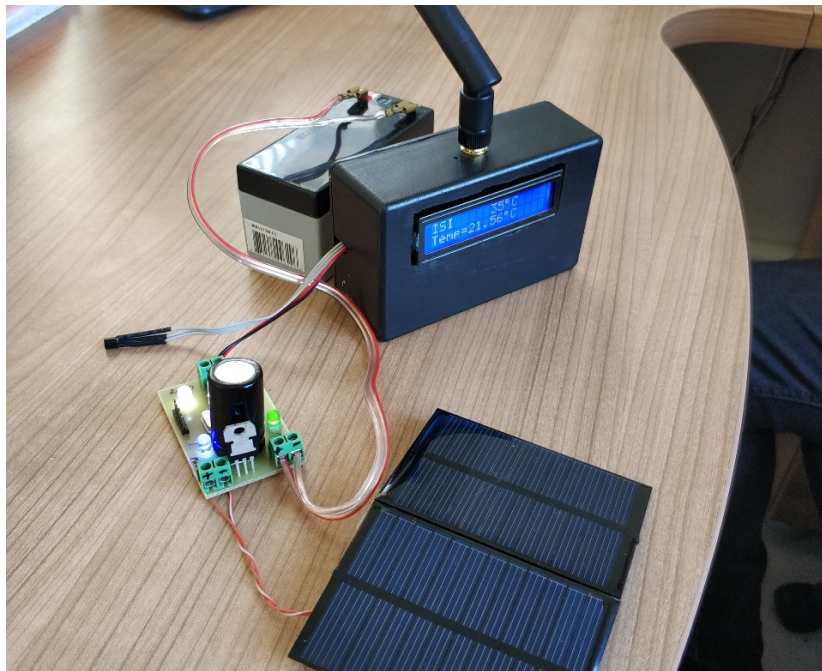*Figure 2.* Diagram of the solar energy harvesting system

Tasks in the in Figure 2 have been evaluated from a new perspective and these tasks have been assigned to the PIC Microcontroller. Architecture of the designed PIC-Controlled solar energy harvesting module is shown in Figure 3. PIC microcontroller deals with power management and coordination of energy resources and it does the tasks given in the diagram above. Voltage circuit will be supported two energy input these are solar panel and rechargeable battery inputs, also voltage circuit will be supported one voltage output to connect WSN sensor nodes.

Figure 3. PIC-Controlled solar energy harvesting module.

### 3.4. General Summary of the Designed Solar Energy Harvesting Module

The designed energy harvesting module which can be examined in some general terms. These are whether or not the designed energy harvesting module that will be able to meet the renewable energy requirements (solar energy, supercapacitor, and battery). The integrated PIC of the designed energy harvesting module will be managed and collected renewable energy. Figure 4 shows the real environment of the developed PIC based energy harvesting module platform with sensor node and renewable energy devices such as solar panel and rechargeable battery.

Figure 4. Overview of the designed PIC-Based voltage module working system for WSN.

3.5. Integrated Renewable Energy Sources to the Solar Module

In the designed solar energy harvesting module, a solar panel is used as the primary energy source for outdoors, with secondary energy storage devices being a rechargeable battery and supercapacitor for all the sensor nodes. Solar panel prices are rising according to the power and characteristics of the solar panel. Designed renewable panel power unit uses a unique power management scheme to coordinate power storage and delivery between a small solar array and rechargeable batteries with a supercapacitor to ensure long network life operations. Connection diagram of the harvesting module to the wireless sensor node is shown in the Figure 5.
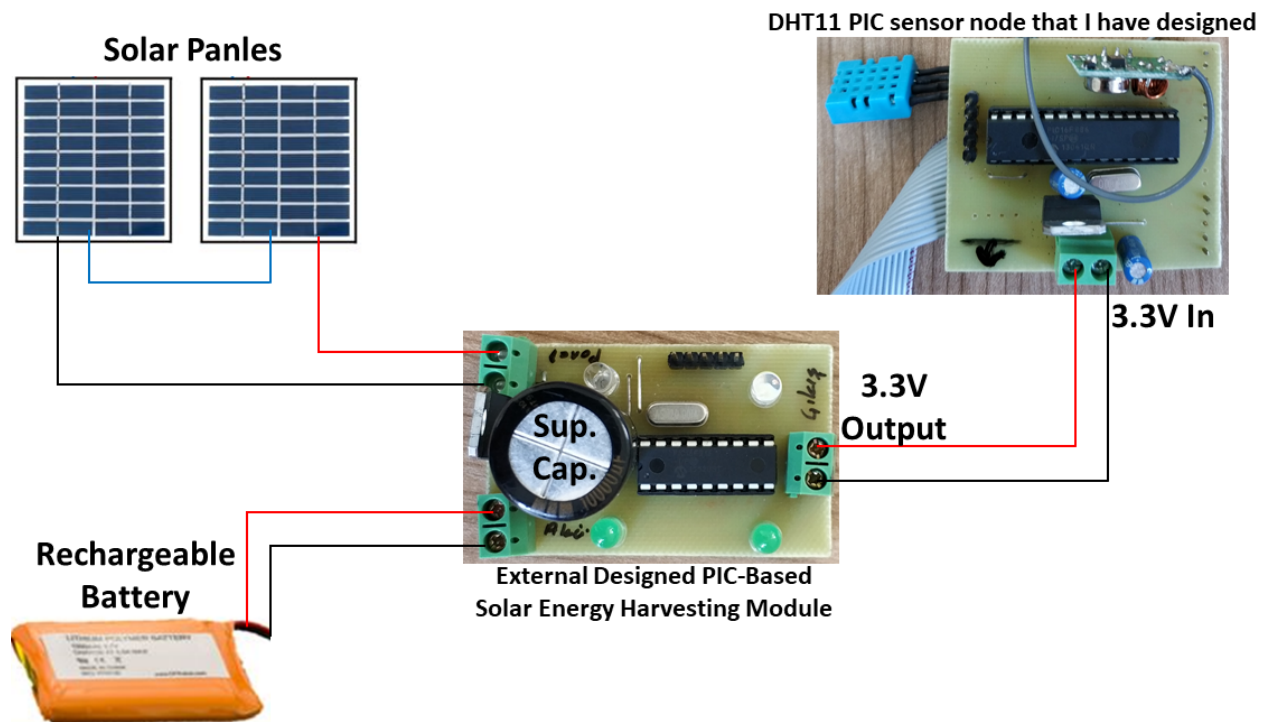
Figure 5. Connection diagram of the harvesting module to the WSN.

Designed DC converter provides an interface to connect to a solar panel, a rechargeable battery and a supercapacitor that provides efficiency across all operating conditions. Designed DC Converter uses less than 470 µA of current and power unit has ability to harvest available solar energy by using the solar array of panels to support all required components. The obtained energy is stored in a 5F supercapacitor and a 350 mAh lithium-ion battery.

Rechargeable Battery	Solar Panel
1.2V	2.0V - 2.5V
2.4V	3.5V - 4.0V
3.6V	5.0V - 6.0V
6.0V	7.5V - 9.0V
12.0V	15.0V - 18.0V

Table 1. Solar panel DC reference table.

We have used a rechargeable battery as an energy storage device for all sensor nodes. Wireless sensor network features the ability to solar energy from the outdoor environment and delivers this energy to the supercapacitor and battery storage devices. Table 1 shows the solar panel DC reference table.

3.6. Microcontroller Used in the PIC-Controlled Voltage Circuit Design

In this study, Microchip PIC16F716 microcontroller is used. The PIC16F716 is 18-pin Flash-based members of the versatile PIC16F716 family of low cost, high-performance, CMOS, fully static, 8-bit microcontrollers. It operates on an advanced RISC architecture. PIC16F716 have enhanced core features, an eight-level deep stack, and multiple internal and external interrupt sources.
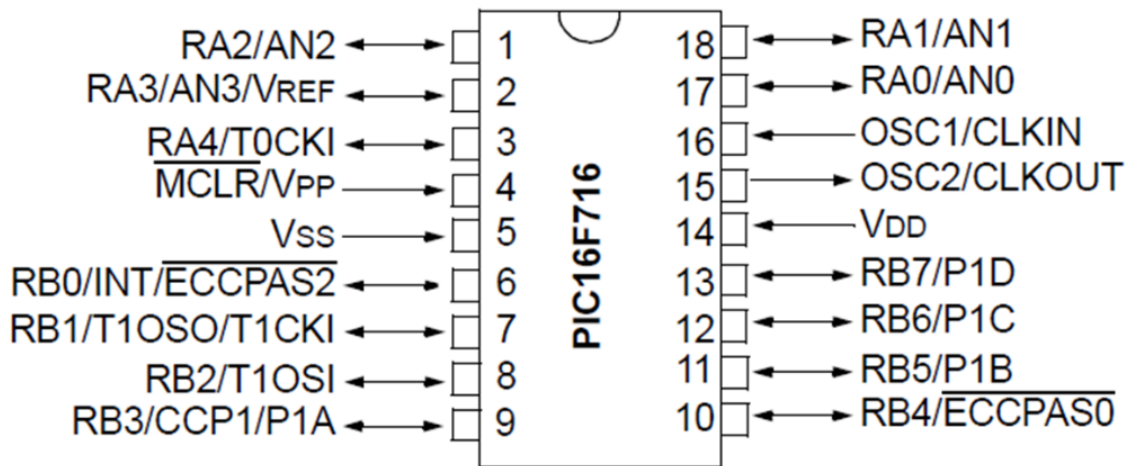
Figure 6. PIN diagram of the PIC16F716 [12].

PIC16F716 devices have also integrated features to reduce external components, therefore reducing system cost, reducing power consumption and enhancing system reliability. Low-power consumption is an important issue in this study. Reduced energy consumption of the components used in wireless sensor networks is very important. So, choice of the microcontroller to be used must be made accordingly.

PIC16F716 fits in applications ranging from battery chargers to low power remote sensors. Low cost, high performance, low power, ease of use and I/O flexibility make PIC16F886 versatile and good candidate for such purposes. PIC16F716 microcontroller properties are shown in the Table 2, also PIN diagram of the PIC16F716 is given in the Figure 6.

| Device	Memory		I/O
	Flash	Data	
PIC16F716	2048 X 14	128 X 8	13
8-Bit A/D (ch)	Timers 8/16	PWM (outputs)	Voltage Range
4	2/1	1/2/4	2.0V - 5.5V

Table 2. PIC16F716 microcontroller properties [12].

3.7. Power Regulator Used in the Voltage Circuit Design

In this study, LM317 voltage regulator is implemented for the power unit. This voltage regulator series of fixed voltage integrated circuit voltage regulators are designed for a wide range of applications. Power unit provides power to the sensor node is shown in the Figure 7.
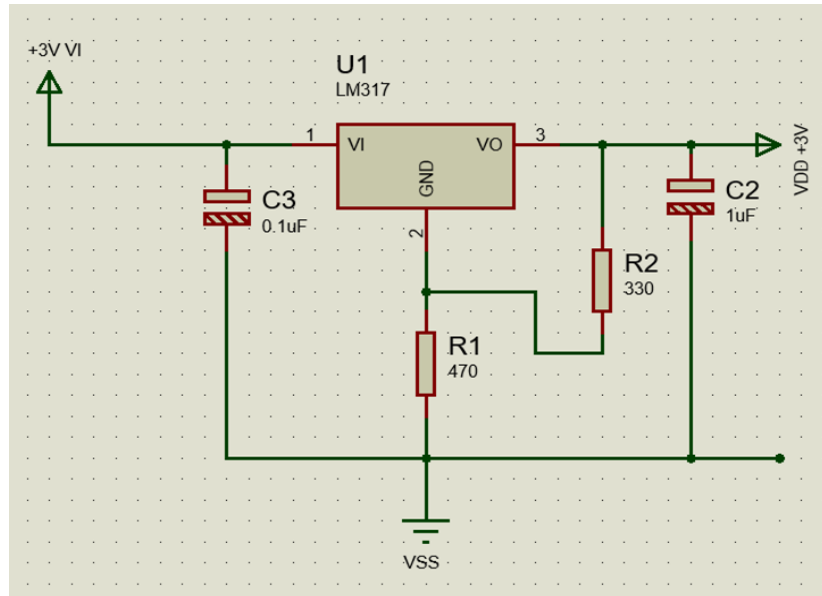

Figure 7. Power Regulator circuit drawing of the Designed solar harvesting module.

The LM317 voltage regulator was implemented on the power unit which includes on-card regulation for elimination of noise and distribution problems. Regulators can deliver up to 1.5A of output current and Output Voltage Range Adjustable from 1.25V to 37V [13]. PIC16F886 microcontroller can operate within the range of 2.0V - 5.5V. FS1000A and XY-MK modules can also operate within the range 3.3V – 12V. Therefore, the wireless sensor node works on 3.3V because PIC microcontroller and wireless communication modules support this voltage.

3.8. Circuit Drawings and Pictures of the Designed PIC-Based Voltage Module

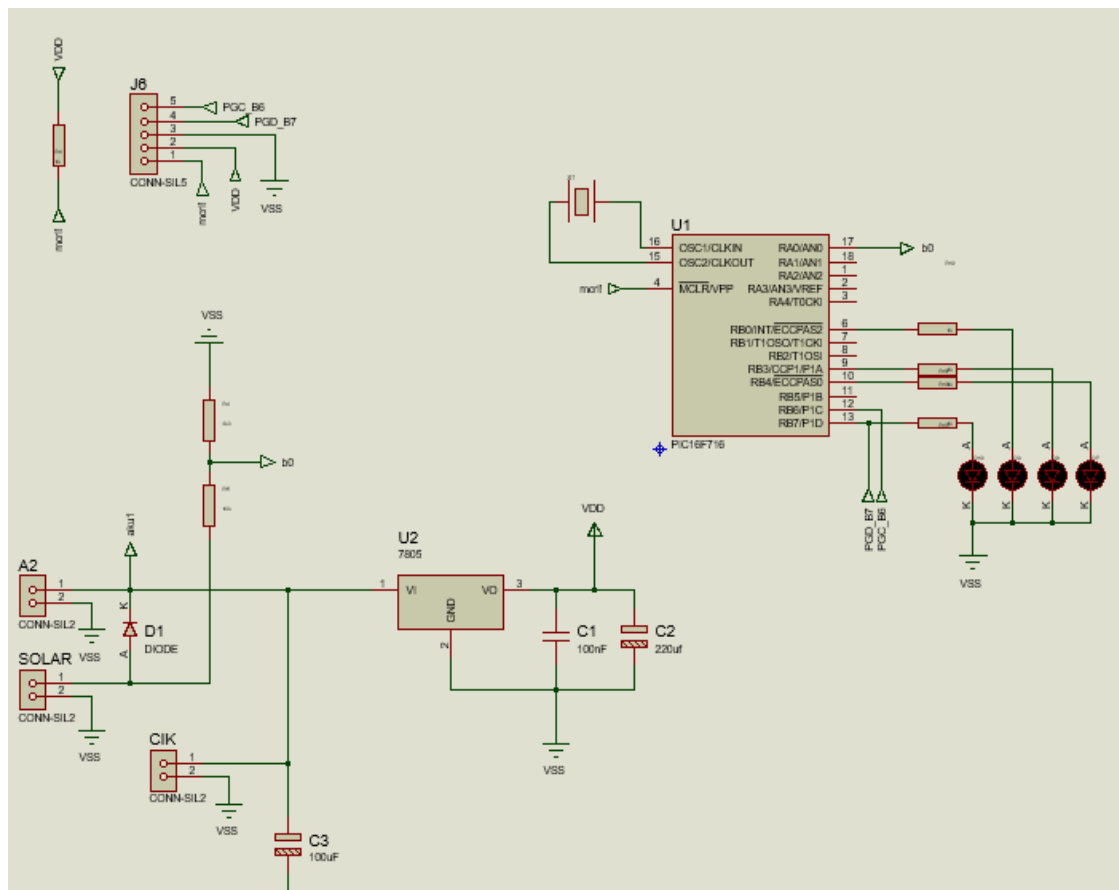The designed solar energy harvesting module for which the bottom view and top view pictures are shown in the Figure 8. Detailed circuit drawing of equipment and links in the designed energy harvesting module platform is given in the Figure 9. PCB layout of the designed harvesting module platform given in the Figure 10.
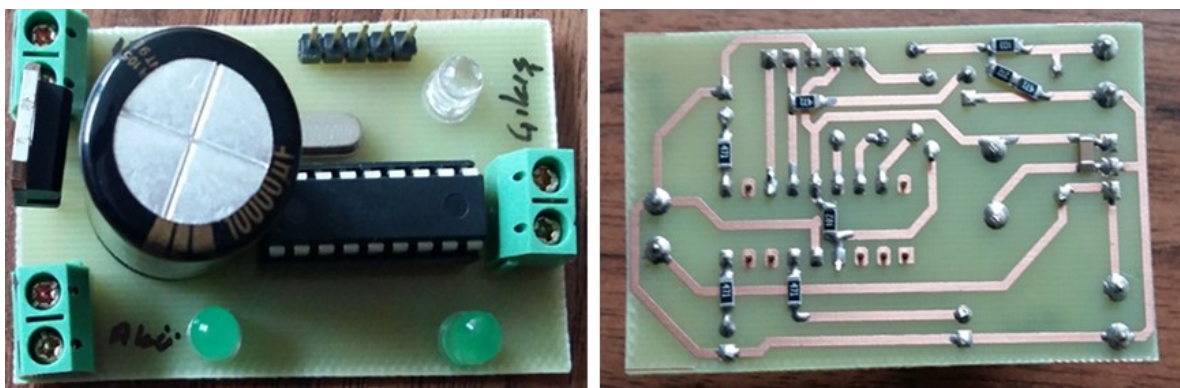
Figure 8. The designed energy harvesting module: bottom view (up) and top view (down).

4. SOFTWARE MANAGEMENT

All operations of the solar energy harvesting module are managed by the operating system and operating system has been developed with PIC-C language. The developed PIC16F716 operating system is responsible renewable solar energy source and power management. In other words, the developed PIC16F716 energy harvesting controller operating system is responsible for managing, collecting and controlling voltage.

Figure 9. Schematic diagram of the designed energy harvesting module.

5. RESULTS AND DISCUSSIONS

The energy consumption of the sensor nodes might change depending on the hardware components and algorithms of managing programs used in the WSN. Wireless sensor node can be designed with the different type of sensor and they consume a different amount of energies. Some of the sensors require a significantly large amount of energy than others such as active sensors, as an example is a radar sensor. Some of the sensors consume little energy such as passive sensors, for example humidity and temperature sensors. Power cost comparison of some popular sensors are given in the Table 3.

We have designed an energy harvesting module which has been tested with wireless sensor nodes including temperature, pressure, humidity and smoke sensors [15]. We have found that the usage of rechargeable battery, supercapacitor and solar panel are crucial because of the high energy consumption of the smoke sensor-gas sensor (MQ2) in wireless sensor networks. Also, we have found that LM35 Temperature sensor node is usable with non-rechargeable battery due to the least energy consumption.

Sensor Types	Power Consumption
Gas Sensor	500mW - 800mW
Image Sensor	150mW
Pressure Sensor	10mW - 15mW
Acceleration Sensor	3mW
Temperature Sensor	0.5mW - 5mW

Table 3. Power cost comparison of some popular sensors [14].

No previous studies have been done on the external solar harvesting module design which can be controlled by the PIC, no PIC-Based voltage-cycling design in literature. Therefore, in this study, completely a separate physical solar energy harvesting module has designed independent from the sensor node. Moreover, PIC microcontroller has integrated into the module for energy saving and power management control. Purpose of designing the module physically independently of the sensor node to increase flexibility and efficiency and to decrease solar energy waste. The designed solar energy harvesting module can be used in any sensor nodes. Designed PIC-Based solar harvesting module can be examined in some general terms. These; designed voltage module that will be met the renewable energy requirements (solar energy, supercapacitor, and rechargeable battery). Integrated PIC of the designed harvesting module will manage and collect renewable energy.

Voltage circuit will be supported by two energy input these are solar panel input and rechargeable battery input, also it will support one voltage output to connect WSN sensor nodes. Table 4 shows the designed external PIC-Based solar harvesting module for controlling solar panel and rechargeable battery and managing the energy consumption.

PIC-BASED ENERGY HARVESTING MODULE FEATURES		
Used Sensor	Used PIC	Voltage Regulator
X	PIC16F716	LM317
Used LCD Panel	Rechargeable Battery & SC	Solar Panel
X	✓	✓

Table 4. Design of the external PIC-Based solar harvesting module.

6. CONCLUSION

In this paper, solar energy harvesting module is designed and investigated for the usage of powering WSN and a new solar powered model for the rapid prototyping of WSN has been presented. The main focus is on the energy conversion efficiency improvement from the prospective of power management and the platform is developed. We have accomplished that design, testing, and successful development of a PIC-Controlled solar energy unit with a supercapacitor, and a rechargeable battery. Solar energy clearly outperforms batteries outdoors and can be an alternative indoors.

For nodes operating continuously, only outdoor solar power can offer a suitable solution whenever small size is required. The goal of acquiring energy from the solar panel by using energy storage components to increase the efficiency is achieved. Designed solar harvesting module is implemented by using energy collection,

energy storage, delivery energy and energy consumption on the sensor nodes. The system is comprised of a solar panel, a lithium battery, and a control circuit are used for charge management of the lithium battery, which improves the reliability and stability of the system. WSN features the ability to harvest available solar energy from the outdoor environment and deliver this energy to the supercapacitor and battery storage devices. It prefers to use the solar energy whenever the sunshine is sufficient, and the lithium battery is a power supply for conditions.

This system can be implemented with small power equipment which is especially suitable for outdoor-based wireless sensor nodes. Real environment results demonstrate that the system can switch the power supply branch automatically. When the voltage of lithium battery drops below the predefined level, it can be charged properly. The solar energy harvesting module works properly and stable with wireless sensor nodes.

The contributions of this paper for the WSN systems are as follows:

• The wireless sensor node works the solar power as the preferential power source as long as the sunshine is available, otherwise it works the rechargeable battery as the primary power source with PIC-Based solar energy harvesting module.
• Designed solar-harvesting module can reduce the complexity of system development, decrease the power consumption, and increase the stability and reliability of the WSN system.
• Charging control of the lithium battery is implemented which supports a reliable and stable operational by the PIC-Based harvesting module to the sensor nodes.
• PIC-Based solar-harvesting module is dominated by solar power using a lithium battery as an energy storage. This architecture extends the life of the battery and the sensor nodes and avoid wasting the solar energy.
• This paper presents a new model of the solar energy harvesting for WSN along with PIC-Based external module to control energy management and the platform is developed as a tool for developers of WSN.
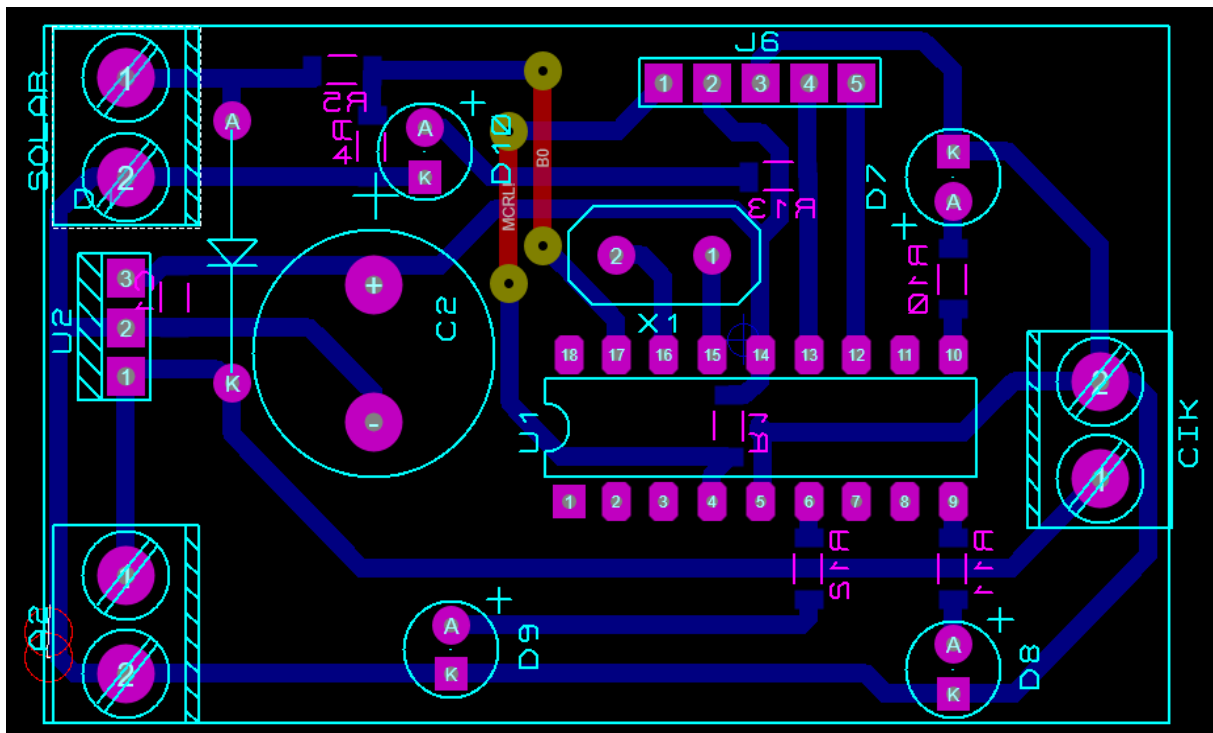

Figure 10. PCB layout of the designed energy harvesting module.

REFERENCES

[1]   Nallusamy, R. and Duraiswamy, K., "Solar Powered Wireless Sensor Networks for Environmental Applications with Energy Efficient Rrouting Concepts: A Review," Inf. Technol. J. 2011, 10, pages: 1–10, 2011.

[2]   Voigt, T., Ritter, H., and Schiller, J., "Solar-Aware Routing in Wireless Sensor Networks," Proceedings of the International Workshop on PWC '03, pages: 847–852, 2003.

[3]   Krupenkin, T. and Taylor, J. A., "Reverse Electrowetting as a New Approach to High-Power Energy Harvesting," Nature Communications, vol. 2, no. 1, article 448, pages: 1–7, 2011.

[4]   Mateu, L., Codrea, C., Lucas, N., Pollak, M. and Spies, P., "Energy Harvesting for Wireless Communication Systems Using Thermo Generators," in Proceedings of the 21st Conference on Design of Circuits and Integrated Systems (DCIS '06), 2006.

[5]   Voigt T., Ritter, H., and Schiller, J., "Utilizing Solar Power in Wireless Sensor Networks". Freie Universität, Institut für Informatik, Berlin, Germany, pages: 1-9, 2006.

[6]   Martino M. and Varley, J., "A Wireless Sensor Node Powered by a PV, Supercapacitor and Battery Trio". The Edward S. Rogers Sr., Department of Electrical and Computer Engineering, University of Toronto, Canada, pages: 6, 2012.

[7]   Hwang, J., Shin, C. and Yoe, H., "Study on Agricultural Environment Monitoring Server System Using Wireless Sensor Networks," Sensors 2010, 10, 11189–11211, 2010.

[8]   Sharma, V., Mukherji, U., Gupta, S, and Joseph, V., "Optimal Energy Management Policies for Energy Harvesting Sensor Nodes," IEEE. Trans. Wireless. Commun, volume 9, Issue 4, pages: 1326–1336, 2010.

[9]   Naveen, K. V. and Manjunath, S., S., "A Reliable Ultra-Capacitor Based Solar Energy Harvesting System for Wireless Sensor Network Enabled Intelligent Buildings," IEEE. 2nd. Int. Conf. Chennai, pages: 20–25, 2011.

[10]   Wu, F., Rüdiger, C. and Yuce, M. R., "Real-Time Performance of a Self-Powered Environmental IoT Sensor Network System," Sensors 17, 282; doi: 10.3390/s17020282, pages: 2-14, 2017.

[11]   Vračar, L., Prijić A., Nešić, D., Dević, S. and Prijić, Z., "Photovoltaic Energy Harvesting Wireless Sensor Node for Telemetry Applications Optimized for Low Illumination Levels," doi: 10.3390/electronics5020026, Electronics, 5, 26, Pages: 1-16, 2016

[12]   MICROCHIP Technology Inc., "8-bit Flash-based Microcontroller with Analog/Digital Controller and Enhanced Capture/Compare PWM". PIC16F716 microcontroller, DS41206B, pages: 1-5, 2007.

[13]   Semiconductor Components Industries LLC. "Literature Distribution Center for ON the Semiconductor, JRev. 14, Publication Order Number: LM317/D", USA, 2016.

[14]   V. K. Sachan, S. A. Imam, and M. T. Beg (2012) "Energy-efficient Communication Methods in Wireless Sensor Networks: A Critical Review". International Journal of Computer Applications (0975 – 8887), Volume 39– No.17, India, pages: 41-44.

[15]   Akgul, B., A., Hasoglu, M., F. and Haznedar, B., "Investigation and Implementation Ultra-Low Power PIC-Based Sensor Node Network with Renewable Energy Source and Decision-Making Unit", Wireless Sensor Network, 10 (2), pages: 41-58, 2018.