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Autonomous Multi Source Energy Harvesting Multi-Sensor

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Abstract

The paper presents the design and implementation of an autonomous multi-sensor system powered by multi-source energy harvesting for structural health monitoring applications. This system monitors the strain of steel structures on ships while collecting environmental data to assess the correlation with steel degradation. It operates autonomously, using both photovoltaic and electromagnetic energy harvesters, and includes an advanced energy management algorithm to optimize power consumption and ensure continuous operation. The paper details the system's architecture, including energy capture, storage, and distribution strategies, and highlights its efficiency and adaptability to variable environmental conditions. It also explores the power consumption of individual components and discusses the results of simulations and bench experiments conducted to validate the system's energy harvesting capabilities. The findings offer valuable insights into energy autonomy for long-term operation in harsh environments, with implications for future advancements in self-powered monitoring systems.

1 Introduction

In today's rapidly evolving technological landscape, the demand for sustainable and self-powered and energy autonomous sensor systems has been intensified. These devices, capable of capturing and utilizing ambient energy from their surroundings, offer a promising solution to the challenges posed by traditional battery-powered systems. By integrating multi-sensor systems, these devices can enhance their efficiency, adaptability, and reliability, enabling a wide range of applications in various sectors. However, the development and deployment of self-powered and energy autonomous sensor systems are not without their challenges. Factors such as environmental variability, energy conversion efficiency, storage and management, cost and scalability, reliability and durability must be carefully considered. Despite these limitations, the potential benefits of these systems are significant.

In this work, we present the design and implementation of a self-powered and energy autonomous multi-sensor system for structural health monitoring applications. Specifically, the system is designed to monitor the strain of steel structures on ships while simultaneously collecting environmental data to investigate their correlation with steel degradation. The system operates autonomously, acquiring and processing data locally before transmitting it to the proprietary platform owned by METIS Cyberspace for storage and further analysis. To ensure perpetual operation, the system incorporates advanced energy management algorithms that optimize power consumption and maximize energy harvesting. The primary objective of

this paper is to introduce the architecture of the proposed system and highlight its unique features in comparison to existing solutions. Additionally, we will delve into the strategies employed to achieve energy autonomy.

The paper is organized as follows: Chapter 2 presents the system architecture, Chapter 3 provides an overview of each subsystem, and Chapter 4 discusses the results and findings. Finally, Chapter 5 sums up and sets implications for future research.

2 System architecture

The system architecture of an energy harvesting system is a crucial aspect that determines its overall efficiency, reliability, and adaptability to different environments. This chapter delves into the design and implementation of the proposed Wireless Autonomous Device System Architecture (WADSA), focusing on its unique power supply architecture. Section 1.1 presents a typical power supply architecture for reference, while Section 1.2 provides a detailed description of WADSA's innovative approach to energy harvesting, storage, and distribution.

2.1. Typical architecture

Figure 1 presents a typical power supply architecture for an energy harvesting system. It illustrates the sequential flow of energy from the source to the load. Ambient energy is captured by harvesters, such as photovoltaic panels or electromagnetic harvesters. A power path controller manages the energy flow, optimizing its distribution and utilization. A DC/DC converter adjusts the voltage to match the requirements of the load. Excess energy can be stored in an accumulator, such as a battery or supercapacitor, for later use during periods of low ambient energy availability. This architecture is commonly employed in autonomous devices and systems that rely on renewable energy sources, offering a sustainable and environmentally friendly power solution.

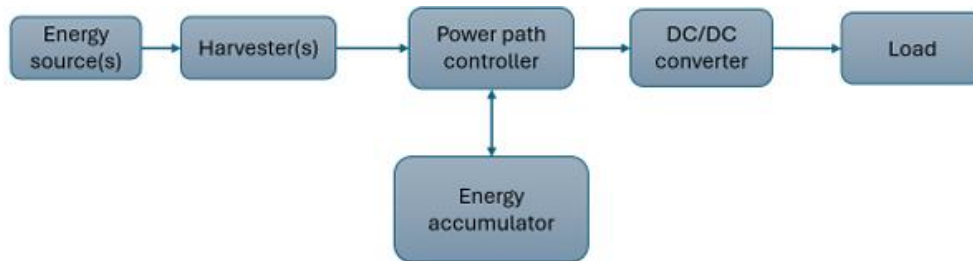


Figure 1: Typical power supply architecture

2.2. WADSA architecture

The system's energy harvesting process is based on integrating multiple energy sources to ensure continuous and reliable power supply. In this design, both photovoltaic (PV) cells and electromagnetic (EM) harvesters are used to capture ambient energy. These energy inputs are managed by a harvester unit (LTC3331), which intelligently controls the flow of energy, directing it to a secondary battery for storage or directly to a supercapacitor for immediate use. The supercapacitor plays a key role in providing quick bursts of energy when needed, while the power gate controller regulates the flow of energy to the load, ensuring efficient consumption. By balancing energy capture, storage, and distribution, this system

ensures that the connected devices can operate autonomously, even in variable energy environments, making it ideal for applications requiring long-term, energy-independent operation.

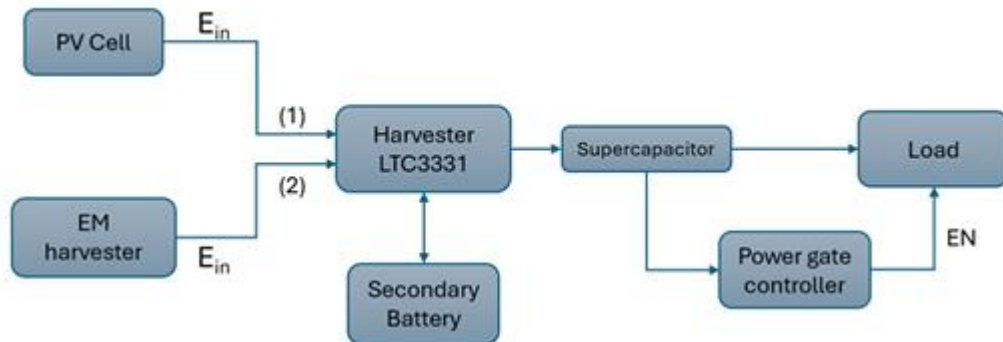


Figure 2: Our power supply architecture

2.3. Application

The main application for the developed system is steel health assessment in naval environments. The used method [1] is a cutting-edge approach that offers a non-invasive way to monitor the strain of steel structures on ships. Unlike traditional methods that require physical access to the steel, this innovative system utilizes advanced sensors to measure strain. This not only minimizes the risk of damage to the steel but also significantly reduces the power consumption required for operation. Additionally, the system is designed to collect environmental data concurrently, allowing for a comprehensive investigation into the relationship between external factors and steel degradation. This dual functionality provides valuable insights for optimizing maintenance schedules and ensuring the structural integrity of ships.

3 Power system design and implementation

Section 3 comprehensively explores WADSA's system design and implementation. This section delves into the intricacies of energy source selection, power management strategies, and multi-source integration.

3.1. Power source and management

The selection of energy sources for WADSA was guided by an evaluation of environmental availability, power density, conversion efficiency, and cost-effectiveness. Indoor light, a ubiquitous and consistent energy source in various indoor environments, was chosen for its potential to provide a reliable and sustainable power supply. The ability of indoor light to penetrate through various materials and its presence in diverse indoor settings made it an attractive option for WADSA's application.

To assess the suitability of different indoor PV cells for WADSA, a comparative analysis was conducted. The power output of several commercially available cells was measured under varying light conditions, as depicted in Figure 3.

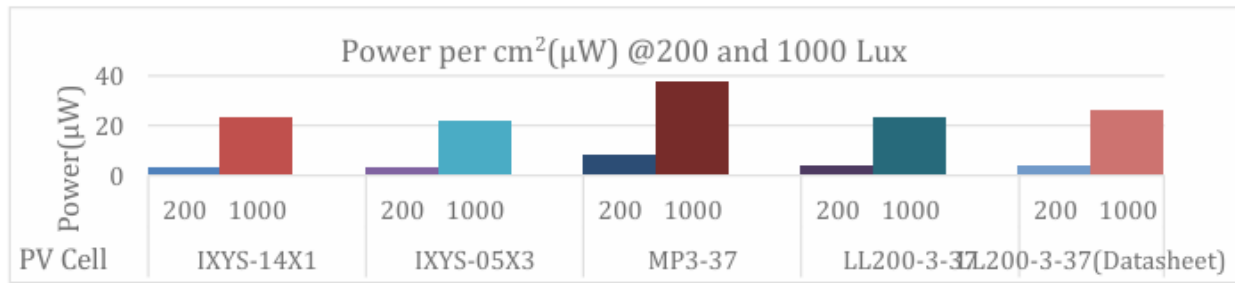


Figure 3: PV cell output at different light intensity

The results indicate that the MP3-37 cell consistently demonstrated superior performance, exhibiting higher power output at both 200 and 1000 lux compared to the other options.

Given that vibrations are abundant in operational ships, the second selected power source for the system were mechanical vibrations. To convert these vibrations into useful electrical power an electromagnetic harvester (EMH) was developed specifically for the needs of the project[2].

3.2. Multi source energy harvesting

In Figure 4, the PCB schematic of the LTC3331 PV + EMH harvesting circuit is presented. A PV cell and an EMH are connected simultaneously to the LTC3331 through connectors J2 and J3. This is a unique configuration, which is not predicted in the literature. As such, the capability of the LTC3331 to receive power simultaneously by PV and EMH is investigated through simulation and bench experiments in section 4.

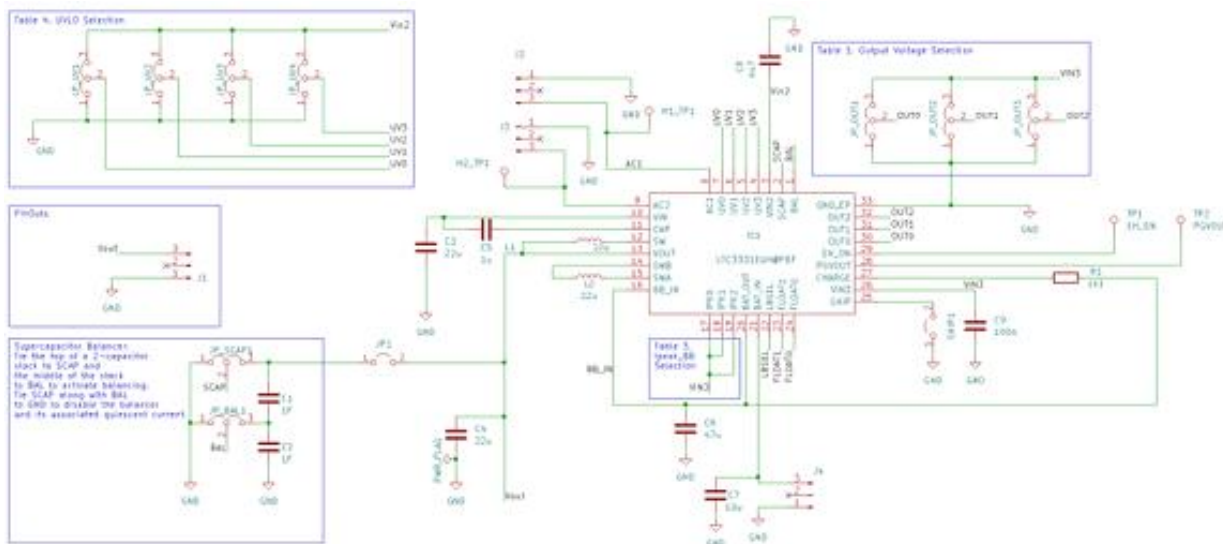


Figure 4: Power supply schematic

3.3. Power consumption analysis

To better understand the power need of the system, a power consumption analysis was conducted. The major components contributing to power consumption are the two microcontrollers, the main

microcontroller that reads the data and the RF module. In Table 1, the power consumption of each system component is depicted.

Component	Operating voltage (V)	Current consumption (mA)	Power consumption (mW)
ESP32-C6_DevKit	3.3	33.3	109.89
ESP32-C6_DevKit (LPM)	3.3	0.208	0.6864
Digi Xbee (Tx)	3.3	35.7	117.81
Digi Xbee (LPM)	3.3	0.141	0.4653
Environmental Sensor	5	15	75
IMU	3.3	13	42.9
Steel stress sensor	3.3	3.6	11.88

Table 1: Component current consumption

The energy required for a single active period of the system is 72.45mJ. To optimize the power consumption, a strategy that adjust the duty cycle was developed. However, the energy management algorithm will not be described in this work.

4 Discussion

5.1. System modeling and simulation

PV and EMH are connected to the LTC3331 at the endpoints of the internal rectifier bridge (connection points AC1 and AC2 in figure 5) and charge capacitor C3 attached to VIN. Figure 5 left is a cutout of the LTC3331 block diagram and Figure 5 right is the equivalent Ltpice circuit of the harvester input. Charge from C1 is transferred to supercapacitors (C1 and C2 in Fig. 4) at the output of LTC3331 (pin VOUT in fig. 4), through inductor L1 of the internal buck converter. For an output of 3.3V, A voltage of 4.4V at C3 triggers the buck converter, which discharges C1 down to approx. 3.6V before stopping. The C3 discharge process re-starts when C3 reaches 4.4V again. The Buck operation/C3 discharge process is simulated in LTspice by a voltage-controlled switch S1 (with hysteresis) and the Rs3 "load" resistor.

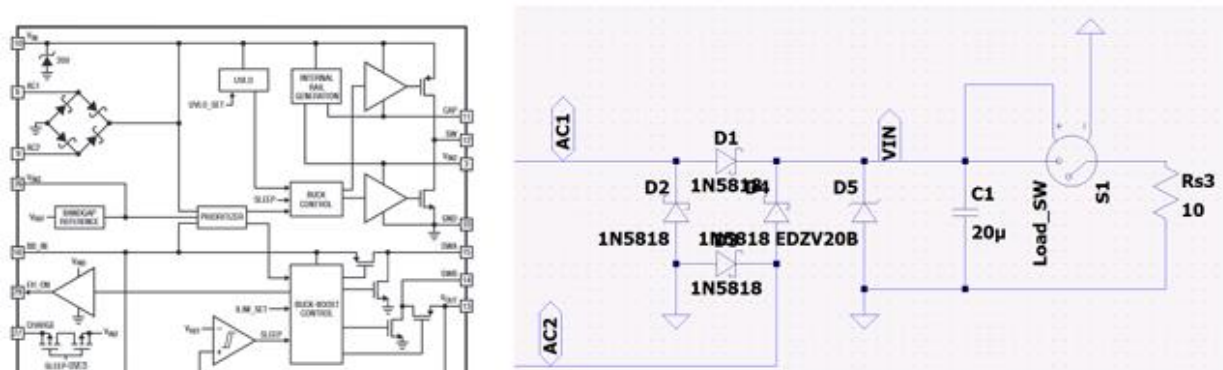


Figure 5: PV cell output at different light intensity

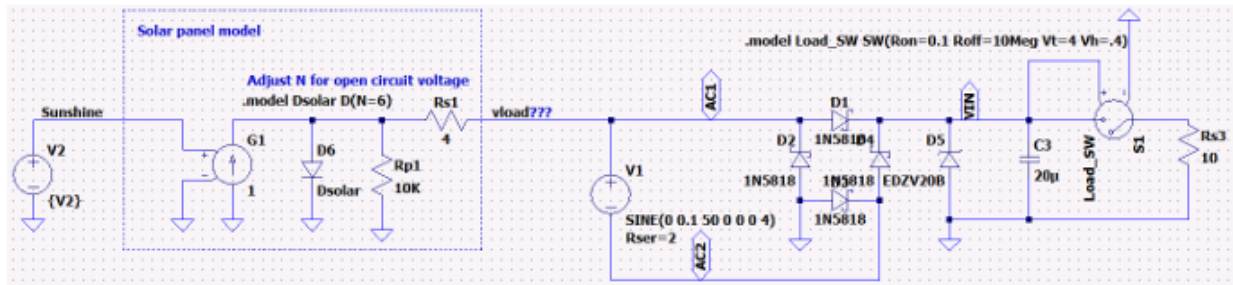


Figure 6. PV Joint PV and EMH operation simulation model

In figure 7, the results of a simulation using two sources at the AC1 and AC2 pins are displayed.

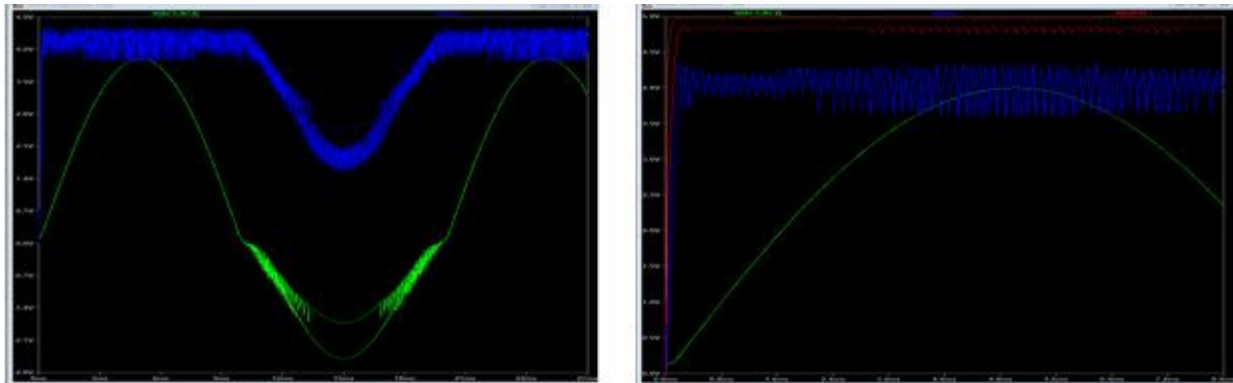


Figure 7. Multi-source simulation

5.2. Bench test and measurements

The experiment was repeated on the bench. The maximum efficiency displayed by the system was 82%. In Figure 8 the bench test is displayed.

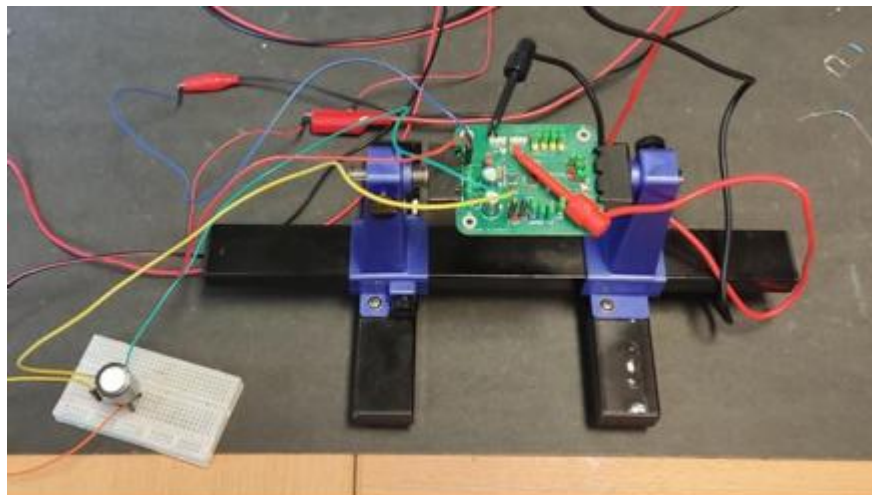


Figure 8. Experimental setup

5 Conclusion

5.1. Sum up

The autonomous multi-source energy harvesting system demonstrated effective performance in energy capture, management, and operational autonomy during bench tests. By integrating photovoltaic and electromagnetic harvesters, the system successfully powered itself while monitoring steel structures in naval environments. The results confirm the system's potential for long-term, self-sustaining operation in harsh conditions.

5.2. Implications for Future Research

Future research could focus on optimizing energy efficiency further and expanding the system's applicability to other structural health monitoring scenarios. Enhancing energy storage capacities and improving adaptability to diverse environmental conditions will enable broader deployment across industries requiring autonomous monitoring solutions.

References

- [1] P. Pattakos, A. Katsoulas, S. Angelopoulos, A. Ktena, P. Tsarabaris, and E. Hristoforou, "Development of an Autonomous Magnetic Permeability Sensor," *IEEE Transactions on Magnetics*, vol. 59, no. 2, pp. 1–4, Oct. 2023, doi: 10.1109/TMAG.2022.3205106.
- [2] P. Pattakos, S. Angelopoulos, A. Katsoulas, A. Ktena, and E. Hristoforou, "Magnetic Harvester for an Autonomous Steel Health Monitoring System Based on Hall Effect Measurements," *Micromachines*, vol. 14, no. 1, Art. no. 1, Jan. 2023, doi: 10.3390/mi14010028.