



Research Paper

Energy Generation from Bio Waste and Utilization with Internet of Things

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Abstract- For control of load remotely, the system which is integrated with both IOT (Internet of Things) and energy generation from bio-waste is designed in this work. Seebeck effect is utilized for conversion of heat generated at TEG (Thermoelectric Generator) to the utilizable electric energy. The electric power generated is measured by INA219 sensor and DC DC boost converter MT3608 has been used to improve the voltage generated by the system. The 16X2 LCD display has been used for displaying the outcomes integrated with Arduino Nano. Cloud platform names SinricPro is used in this application with wifi module, ESP8266 for IOT based communication. For generating energy continuously, different other things such as fan, pump, arrangement of water cooling are utilized in this application. This application can control IoT based load and monitor system continuously for generation of electrical energy from the waste heat. So the proposed system can be used in applications where low power is needed by providing sustainable and easy solutions for bio-waste heat.

Index Terms- Harvesting of Energy, Generating thermoelectric Energy, IoT (Internet of Things), ESP8266, Arduino Controller, Energy from Bio-waste.

I. INTRODUCTION

The proliferation of distributed sensors, wireless control units and connected devices has placed the power sources on demand for being small and reliable. Meanwhile, a significant proportion of the heat generated from combustion and industrial processes is wasted by being released to the environment as low and medium energy heat. Even if only a fraction of this energy can be recovered, it could be used for low-power sensing, monitoring and control and enhance the use of all the energy resources available locally. For this the thermoelectric generators are interesting because they are solid-state and have no moving parts; they transform a temperature difference into an electrical current directly by the Seebeck effect. In recent years, the application areas of thermoelectric conversion which have been pointed out through literature review include waste heat recovery and autonomous IoT nodes. [1]-[10].

Bio-waste is very relevant in rural, agricultural, food-processing and decentralised energy contexts as residues that are not used for anything can be efficiently transformed into useful heat. Previously, thermoelectric recovery from biomass engines and biomass heated equipment has been shown [1] and [2]. The electrical output from a TEG is, however, highly sensitive to effective temperature gradient, thermal contact, electrical loading and power-conditioning strategy. In practical systems, however, it is necessary to consider thermal management, sensing, power electronics, and the profile of the load simultaneously, not in isolation as the TEG [3] [5] [6].

The present work builds an integrative prototype based on this system level perspective. The intent is to generate heat from bio-waste; however, when operating on a bench in a controlled environment, a stable flame-based heat source is used to simulate the hot-side heat flux, so that the conversion, monitoring, cooling, and IoT-control subsystems can be tested without the variation of combustion. The hardware in the prototype consists of a TEG module, an MT3608 boost converter, INA219 current/power sensing, an Arduino Nano local monitoring node, a 16x2 display LCD module, an ESP8266 Wi-Fi module, a dual relay module, LED/fan loads, and an auxiliary 5-V supply for lab testing. An important separation for science: the prototype does not claim that all controls and cooling components are powered by the TEG, but it does show how the TEG can be used to harvest energy to monitor and drive controls and cooling.

The contributions of the work are three-fold. The three-fold contributions of the work are. First, it combines bio-waste friendly thermoelectric harvesting with electrical sensing, display, and cloud connected load control in one bench scale architecture. Secondly, it

applies the explicit cold side thermal management to maintain the temperature difference of the TEG during the process, and applies the process of pre-conditioning the output voltage before measurement and utilization. Third, it publishes a real observed electrical operating point and addresses the discrepancy between the multiplication of the voltage current at the instant of its measurement and the sensor power displayed. The rest of the paper summarizes previous research, introduces the system model, and its implementation, reports on experimental experiences, and describes the measurements needed for journal quality performance verification.

II. RELATED WORK

Goswami and Das studied thermoelectric recovery from a biomass heat engine and proved that a significant electric power can be recovered from the biomass waste heat if the thermal interface is designed judiciously [1]. Similarly, Jayanegara et al. identified the TEG modules on a biomass egg-drying system and demonstrated the close relationship between the voltage and power generated and the available temperature difference [2]. The studies suggest biomass/bio-waste thermal processes to be used as an alternative source of thermoelectric harvesting instead of electrochemical source.

At the system level, Zaferani et al. pointed out that the performance of thermal energy conversion with TEGs depend not only on material properties but also on heat transfer and thermal boundary conditions [3]. Ochieng et al. reported on TEG in thermal energy consuming processes [5] and Olabi et al. presented an overview of TEG applications and practical design challenges for various waste heat scenarios [6]. These works facilitate the application of active or passive cooling systems for a hot side/cold side temperature difference maintenance.

For IoT nodes, the authors of [4] demonstrated the feasibility of thermoelectric energy harvesting for LoRaWAN devices, and proved that a proper temperature difference and an energy-management strategy can enable frequent communication. Xie et al. presented an overview of thermoelectric-powered sensors for IoT applications and discussed its advantages of energy autonomy, and Liu et al. conducted experimental studies on the operation of TEG at low temperature difference [8], [9]. Alvarez-Carulla et al. also presented a highly efficient design of a thermal monitoring wireless sensor node powered by itself [10]. All of these studies suggest that the most promising approach to autonomy is to design a system that works together: duty-cycled electronics, buffering or storage, low loss converter, and TEG.

The present prototype is unique in that it incorporates two functional paths: a measurement path where the electrical parameters of the body are recorded, and a control path that enables remote control of useful loads. The INA219 is used to monitor the bus-voltage/current/power digitally [13], [14] and the ESP8266 is used for Wi-Fi communication and relay switching. The command interface from the cloud is supplied by SinricPro, which is then used to send ON/OFF requests to the relay controlled loads [15].

III. SYSTEM DESIGN AND METHODOLOGY

A. Operating Principle

A thermoelectric module is a stack of p and n legs of semiconductors that are electrically serially connected and thermally parallel-connected. If there is a difference between the hot-side temperature T_h and the cold-side temperature T_c , the net Seebeck voltage V is roughly linear with the temperature difference. V is the voltage measured as a result of the module containing multiple thermocouples. V is the voltage measured when there are multiple thermocouples in a module.

$$V_{oc} = N(\alpha_p - \alpha_n)(T_h - T_c) \quad (1)$$

where N is the effective number of thermocouple pairs and α_p and α_n are the Seebeck coefficients of the p-type and n-type legs—shows that the change in thermocouple voltage is directly proportional to the product of the Seebeck coefficients.

The available voltage then goes down when the cold side is brought closer to the temperature of the hot side. This thermal equalization is minimized by the water loop, pump, heat sink and fan in the prototype and helps to maintain

$$\Delta T = T_h - T_c.$$

From an electrical point of view, the TEG can be modeled as a Thevenin voltage source V_{oc} in series with an internal resistance R_{int} . The load voltage and power are

$$V_L = V_{oc} R_L / (R_{int} + R_L) \quad (2)$$

$$P_L = V_L^2 / R_L \quad (3)$$

The optimum power transfer is at the point where R_L is approximately equal to R_{int} , but actual systems also have converter loss, wiring loss, relay contacts and the dynamic input impedance of electronic load components. Therefore, a DC-DC conversion stage is added to boost and stabilize the bus voltage that is usable for measurement and utilization, as shown in Figure 7. Thus, a DC-DC conversion stage is

employed to increase and stabilize the useable voltage of the bus for measurement and utilization, as shown in Figure 7

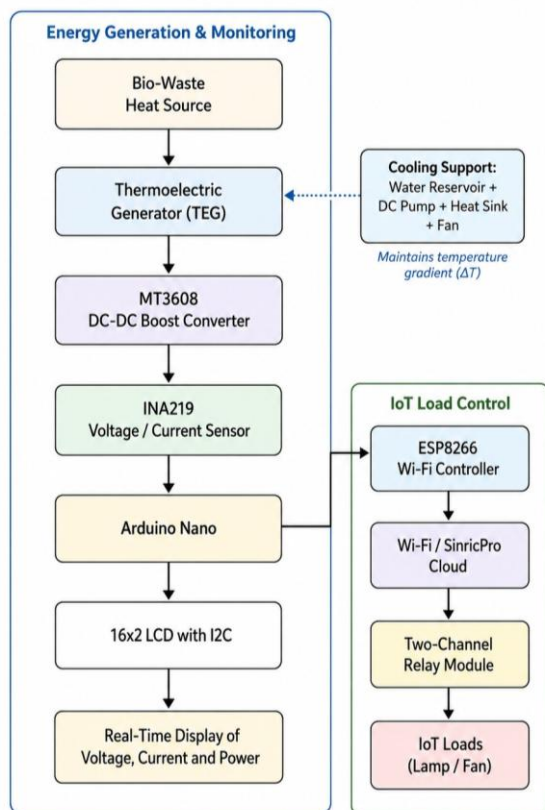


Fig. 1. Proposed system architecture for bio-waste thermal-energy harvesting, local monitoring, and IoT-enabled load control

The prototype has been corrected physically to be presented as summarized in Figure 1. The bio-waste derived thermal source is connected to the hot side of the TEG while the water cooling arrangement keeps the cold side of it. The output of the TEG is fed into the MT3608 converter and sensed by the INA219. The Arduino Nano is reading the sensor and updating the LCD via the I2C. At the same time, the ESP8266 is responsible for keeping the WiFi connection to SinricPro alive and activates the dual relay module. The detailed circuit and the photo of the actual set-up agree with this hardware split, with the Nano doing the local measurement/display and the ESP8266 doing the networked actuation.

C. Measurement and Local Display.

The INA219 is a 12-bit I2C current/power monitor capable of measuring the bus voltage and shunt current, and can compute the power after calibration [13]. The controller takes the bus voltage V_b and the load current I_b for each measurement cycle. The electrical power is independently estimated from

$$P_{\text{calc}} = V_b I_b \quad (4)$$

and can be compared to the power P_{sens} reported by INA219. This comparison can be helpful to detect errors at the unit level, calibration mismatch, asynchronous screen updates or rounding too much. LCD offers instant local visibility even in the absence of a cloud connection.

D. IoT Control Path

The ESP8266 is a 2.4-GHz Wi-Fi system-on-a-chip, which is a popular choice for low-cost IoT controllers [14]. It is used in the prototype to connect to the configured Wi-Fi access point and create the SinricPro session. A cloud callback translates the desired state of the device to the corresponding relay channel, enabling the user to switch energized or de-energized loads from the mobile/web interface. Relay isolation also provides the ability for the low voltage microcontroller to control loads whose current demand is larger than the GPIO pin rating. The SinricPro relay-control workflow is similar to its published ESP8266 switch tutorial [15]

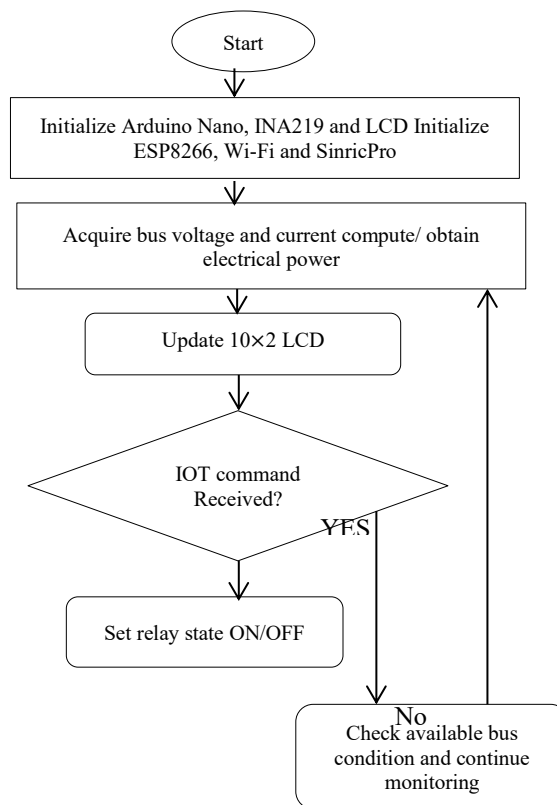


Fig. 2. Monitoring and IoT load-control flow used in the prototype.

Once it's started up, the local controller then reads the voltage and current data and calculates the power usage, then redraws it. At the same time, the ESP8266 is responsible for the cloud connection and for performing relay commands when they come in. The monitoring loop will run whether or not a new command is available. A future undervoltage lockout for cloud actuation can be added where the buffered energy is adequate during an active cloud actuation.

IV. HARDWARE IMPLEMENTATION

A. Hardware Components used:

Proposed prototype system uses multiple hardware components such as,

- DC-DC boost Converter, MT3608
- Arduino Nano Controller
- Power Monitoring using INA219 I2C
- 16x2 LCD display
- Wi-Fi module, ESP8266
- Load switching using relays
- Fan, circulation loop, water pump

B. Electrical Interconnection

Below is the electrical interconnection of components used in this application are shown,

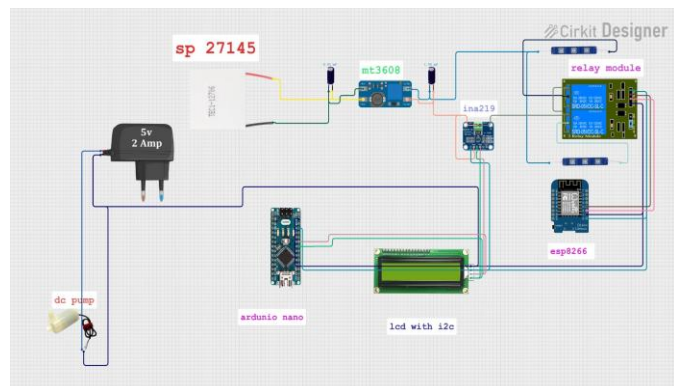


Fig. 3. Electrical Interconnection is shown between various hardware components used in Proposed System

In the above figure, electrical interconnections between multiple components used in this application are shown which provides 2 types of information about though proposed system. One is the raw voltage obtained from the system output is given to the boost converter to improve the output voltage and the second one is Adapter used can be the auxiliary source. Hence the proposed system can be used in utilization of IoT as well as harvesting the heat generated in bio waste.

C. Assembling Mechanical and Thermal related Components

Below picture shows a prototype which is designed by considering mechanical as well as thermal behavior of the components and their specific arrangement to achieve though proposed outcome.

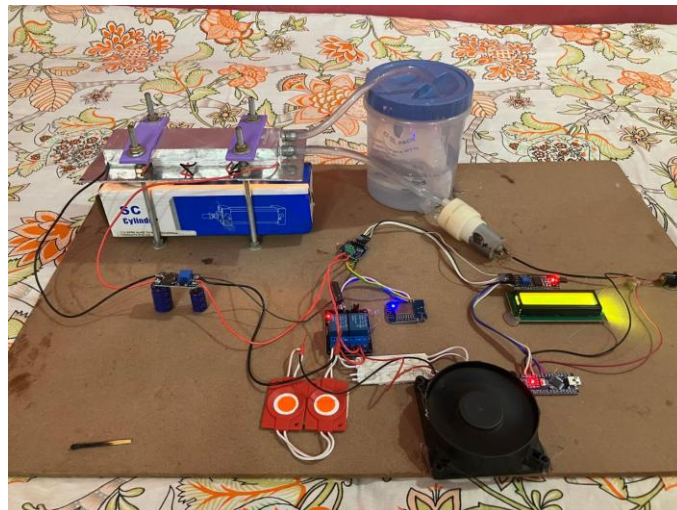


Fig. 4. Components Assembled Mechanically and Thermally

The metal block which is cooled and the interface which is heated provides the thermoelectric system which is arranged or assembled in the mechanical way. Rejection of the heat is handled by forced air cooling while at the cold side for circulating the water DC pump has been used. Unwanted heating is reduced by segregating electronics part and thermal way. So instead of using gasified outlet and combustion chambers, conversion of heat to electric arrangement is properly designed as well as validated.

V. RESULTS & DISCUSSION

A. Functional Validation

There are three validations applied to check the proposed method functionality,

- generation of thermal to electric Power
- Monitoring and Displaying outcomes
- IOT application: WiFi relay actuation

INA219 is used for monitoring the electrical parameters, the cooling part is active, and sources of thermal energy are used which are displayed on LCD the values obtained at the operating point. Wifi based load control can be used, which is the IoT application mentioned in this application and the controller ESP8266 is used.

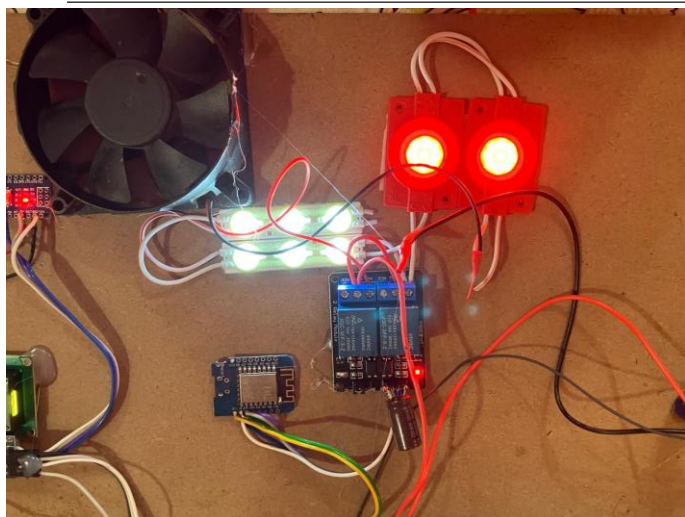


Fig. 5. Functional testing for ESP8266 on load side which is relay controlled with switches

In the above figure shows the controlled load section can be seen and while testing functionally There is a checking of switches and the controller used is ESP 8266.

B. Representative Electrical Observation

Below is the output displayed on 16X2 LCD display.

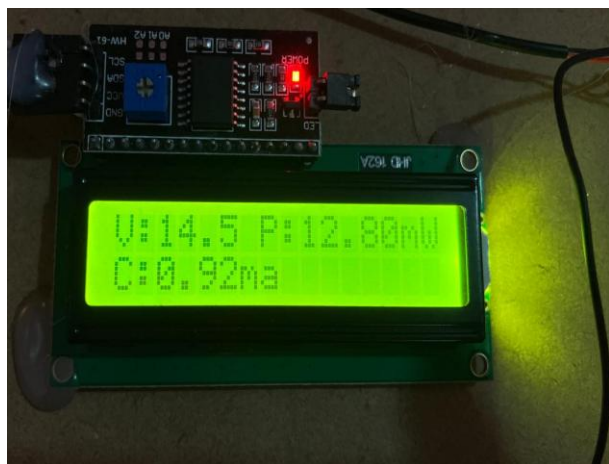


Fig. 6. 16x2 LCD Display to display the Electrical Parameters

In the above test of experiment values obtained are,

- Current value is 0.92 ma
- Voltage value is 14.5 V
- Power is 12.80 mW

The formula used for power calculation from current and voltage value is

$$P = V * I \dots \dots (1)$$

Where,

‘P’ is Power generated in Watt

‘V’ is the voltage in Volts

‘I’ is current in Amperes

So, the electrical energy obtained is shown in the above details, parallelly there are many other metrics that can be calculated in future such as temperature at cold side and hot side, accuracy of sensors used, thermoelectric energy value at generator, voltage obtained in simultaneous way, etc.

C. Discussion

The voltage on the bus is actually higher than typical of a single low gradient TEG (without conditioning), which corresponds to the MT3608 boost stage in the electrical schematic. The experiment therefore proves the validity of a conditioned electrical bus, rather than of a raw TEG voltage characteristic. This distinction is crucial because it allows them to compare the result with the previous thermoelectric studies [1], [2] and [9]. When the raw TEG terminals are measured before the converter, they should be included in the characterization of the generator with the converter input/output efficiency to get a true characterization.

It is also important to the result that the thermal design is centred. The greater the increase in the cold-side temperature, the smaller the ΔT will be, and the less the thermoelectric voltage will be. The water loop and fan thus play an indirect role in the electricity output, by rejecting the heat on the cold side. Also, from the prior reviews, it is noted that thermal interfaces and heat exchangers may be a limiting factor in the practical TEG performance [3] [5] [6]. If implemented as a bio-waste, the hot-side exchanger should also be designed to ensure that the TEG never reaches temperatures outside the allowable range; while also ensuring that the thermal contact resistance is minimised.

The IoT subsystem gives functionality but also takes power. The ESP8266 datasheet provides significantly higher current consumption during Wi-Fi transmitting compared with the current consumption during Wi-Fi idle [14]. A fully autonomous node should not be powered on all the time via a weak TEG source, then, for this reason. Some practical solutions are an energy buffer of a supercapacitor or rechargeable cell, deep-sleep mode, event-dependent transmission, using a low-power radio, or an energy-harvesting power-management IC with a cold-start. The changes would make the current demonstrator into a sustainable energy conscious IoT node, in line with the trend in the thermoelectric IoT literature [4] [8] [10]-[12].

VI. ADVANTAGES, LIMITATIONS, AND DESIGN IMPLICATIONS

The advantage of proposed method is generating electrical energy from the waste heat, current and voltage monitoring, IoT based control of electrical loads. Proposed prototypes can be used for smaller level applications by utilizing energy of bio waste such as monitoring environmental parameters, basic control-based applications, lighting with low power requirement, monitoring different equipment.

There are some limitations in the proposed prototype such as there is no measurement of temperature on cold side and hot side in the generator of thermoelectric energy and due to this different performance metrics are not able to analyze such as thermal parameters, efficiency of conversion, differences in temperature, etc. similarly there are IoT metrics are also need to calculate such as time of reconnection, losses present in the connection, delay in communication. These limitations can be further overcome using new updated realistic system.

VII. CONCLUSION AND FUTURE WORK

Bio waste-based energy generation system has been successfully designed using control system of IOT load and energy harvesting of thermoelectric which is bench scale. Electrical energy has been obtained from the thermal gradient with the help of TEG and using Arduino Nano controller, operating outcomes are shown on LCD display which is 16X2 as well as remote loads are controlled using SinricPro with ESP8266. Thermal management is performed using a fan and loop with water circulation is the final prototype designed. With multiplication we obtained 13.34 mW which is obtained from the 0.92 mA and 14.5 V, this value is shown in display of sensors in comparison to 12.80 mW. For validating functionally, the difference obtained is smaller. In a single prototype the integration of IOT based actuation, monitoring electrical system, heat harvesting are observed which makes system more efficient and robust.

Future work can be a prototype which can be used in real life with practical applicability as well as better performance. To run under operating conditions which are realistic there is need of combustion chamber of biowaste in replacement of heat source present in system. To monitor difference in temperature, temperature sensors can be used on cold as well as hot side. Performance dashboard can be created to monitor the electrical outputs. For IoT based modules efficient circuit of power management as well as storage unit for the energy can be additionally used to make system more reliable as well as available for long duration.

REFERENCES

- [1] R. Goswami and R. Das, "Waste heat recovery from a biomass heat engine for thermoelectric power generation using two-phase thermosyphons," *Renewable Energy*, vol. 148, pp. 1280-1291, 2020, doi: 10.1016/j.renene.2019.10.067.
- [2] S. Jayanegara, Z. Djafar, Z. Djafar, N. Azis, and W. H. Piarah, "The characterization of thermoelectric generator in utilizing the heat waste of the biomass egg drying machine," *EPI International Journal of Engineering*, vol. 3, no. 1, pp. 30-33, 2020, doi: 10.25042/epi-ije.022020.04.
- [3] S. H. Zaferani, M. Jafarian, D. Vashae, and R. Ghomashchi, "Thermal management systems and waste heat recycling by thermoelectric generators-an overview," *Energies*, vol. 14, no. 18, Art. no. 5646, 2021, doi: 10.3390/en14185646.
- [4] I. Cappelli, S. Parrino, A. Pozzebon, and A. Salta, "Providing energy self-sufficiency to LoRaWAN nodes by means of thermoelectric generators (TEGs)-based energy harvesting," *Energies*, vol. 14, no. 21, Art. no. 7322, 2021, doi: 10.3390/en14217322.
- [5] A. O. Ochieng, T. F. Megahed, S. Ookawara, and H. Hassan, "Comprehensive review in waste heat recovery in different thermal energy-consuming processes using thermoelectric generators for electrical power generation," *Process Safety and Environmental Protection*, vol. 162, pp. 134-154, 2022, doi: 10.1016/j.psep.2022.03.070.
- [6] A. G. Olabi et al., "Potential applications of thermoelectric generators (TEGs) in various waste heat recovery systems," *International Journal of Thermofluids*, vol. 16, Art. no. 100249, 2022, doi: 10.1016/j.ijft.2022.100249.
- [7] Q. Zhang, K. Deng, L. Wilkens, H. Reith, and K. Nielsch, "Micro-thermoelectric devices," *Nature Electronics*, vol. 5, pp. 333-347, 2022, doi: 10.1038/s41928-022-00776-0.
- [8] H. Xie, Y. Zhang, and P. Gao, "Thermoelectric-powered sensors for Internet of Things," *Micromachines*, vol. 14, no. 1, Art. no. 31, 2023, doi: 10.3390/mi14010031.
- [9] Y. Liu, J.-R. Riba, M. Moreno-Eguilaz, and J. Sanllehi, "Application of thermoelectric generators for low-temperature-gradient energy harvesting," *Applied Sciences*, vol. 13, no. 4, Art. no. 2603, 2023, doi: 10.3390/app13042603.
- [10] A. Álvarez-Carulla, A. Saiz-Vela, M. Puig-Vidal, J. López-Sánchez, J. Colomer-Farrarons, and P. Ll. Miribel-Català, "High-efficient energy harvesting architecture for self-powered thermal-monitoring wireless sensor node based on a single thermoelectric generator," *Scientific Reports*, vol. 13, Art. no. 1637, 2023, doi: 10.1038/s41598-023-28378-6.
- [11] T. Kucova, M. Prauzek, J. Konecny, and D. Andriukaitis, "Thermoelectric energy harvesting for Internet of Things devices using machine learning: A review," *CAAI Transactions on Intelligence Technology*, vol. 8, no. 3, pp. 680-700, 2023, doi: 10.1049/cit2.12259.
- [12] C. Lenz, S. Vostrikov, P. Mayer, and M. Magno, "From heat to power: Assessing thermoelectric energy harvesting for self-sustainable sensors," in *Proc. 2023 IEEE International Workshop on Technologies for Defense and Security (TechDefense)*, 2023, doi: 10.1109/TechDefense59795.2023.10380941.
- [13] Texas Instruments, "INA219 Zero-Drift, Bidirectional Current/Power Monitor With I2C Interface," INA219 datasheet, Rev. G, 2014.

- [14] Espressif Systems, “ESP8266EX Datasheet,” ver. 7.1, 2025.
- [15] SinricPro, “Switch Tutorial Part 1-Turn on and off a Relay,” SinricPro Documentation, accessed Aug. 28, 2026.