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DEVELOPING LAB PROCEDURES FOR IoT POWER MANAGEMENT USING SLEEP MODE: AN OBE APPROACH FOR TVET EDUCATION

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Abstract:

As awareness of the importance of energy efficiency in Internet of Things (IoT) systems is increasing, there is a need for educational tools that promote sustainable technology practices. In this paper, a laboratory procedure for power management using sleep mode on microcontroller-based Internet of Things devices is developed. This laboratory procedure is specifically designed for students in Technical and Vocational Education and Training (TVET) institutions studying IoT. A microcontroller, ESP32 and a temperature sensor, DHT11 are used as an IoT system that monitors temperature by sending to the cloud, Thingspeak. While another ESP32 and a current sensor, INA219, are used to measure power consumption in active, light sleep and deep sleep modes, and the current data is sent to Excel. Experimental results show that using sleep mode strategically can result in significant power savings and energy efficiency gains supported by quantitative data. A laboratory framework that is in line with the principles of Outcomes-Based Education (OBE) and the relevant Sustainable Development Goals (SDGs), specifically SDG 7 (Affordable and Clean Energy) and SDG 12 (Responsible Consumption and Production), is proposed based on these findings. Clear Course Learning Outcomes (CLOs), assessments with an emphasis on sustainability, and a CLO- Course Learning Outcomes (PLO) mapping structure that can be incorporated into current TVET curricula are all features of the lab design. This framework creates a foundation for future implementation and evaluation, despite the lack of data on student learning outcomes. This work offers a pedagogical model that promotes energy-conscious engineering education in addition to technical analysis of IoT power optimization.

Keywords:

Sleep Modes, Energy Efficiency, IoT, Lab Procedure, TVET, OBE

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Introduction

The Internet of Things (IoT) has rapidly become a keystone of modern technological development, enabling a vast network of interconnected devices to collect, process, and exchange data autonomously. However, the explosion of IoT devices has introduced significant challenges, particularly in terms of energy consumption and power efficiency. Many IoT applications are deployed in remote or battery-powered environments where power availability is limited, making low-power design a critical requirement (Haimour & Abu-Sharkh, 2019; Osolinskyi et al., 2022). Despite this, many educational institutions and Technical and Vocational Education and Training (TVET) programs continue to focus primarily on the functional aspects of IoT, such as integrating sensors, transmitting data to the cloud, and developing end-user applications (Sona College of Technology, 2025; University of California, 2025; Valencia Polytechnic University, 2024). While these are essential skills, energy optimisation, an equally critical design consideration, is often overlooked in curricula. Built-in microcontroller features like sleep modes, frequency scaling, and peripheral control are frequently ignored, even though they are crucial for real-world, sustainable IoT system design.

One of the most effective strategies for reducing power usage in microcontroller-based systems is the implementation of sleep modes, which significantly lower energy consumption during idle periods. Microcontrollers like the ESP32 offer various low-power states such as deep sleep and light sleep that can extend battery life in IoT applications by several fold (Espressif Systems, 2021; Hakim et al., 2022; Samuda et al., 2023). However, the absence of practical, lab-based instruction on energy-efficient techniques means students often graduate without this critical skill. To bridge this gap, there is a growing need to embed energy-conscious thinking into the engineering and technical curriculum. TVET institutions play a key role in preparing students with hands-on, industry-relevant skills. Integrating sustainability into TVET requires an educational model that goes beyond knowledge delivery. It must emphasise measurable outcomes, skill application, and societal relevance. This is where Outcome-Based Education (OBE) becomes essential. OBE ensures that learning activities and assessments are aligned with clearly defined outcomes, such as technical skills, critical thinking, and sustainability awareness (Syeed et al., 2022; Zhang, 2021).

In this context, the aim of this paper is to develop and evaluate a lab procedure focused on power-saving techniques using sleep modes in IoT devices. The lab is designed not only to teach students how to implement and measure energy-efficient techniques but also to align with OBE principles and promote values related to the Sustainable Development Goals (SDGs), particularly SDG 7 - Affordable and Clean Energy and SDG 12 - Responsible Consumption and Production (Nations, 2023). Through this approach, the paper seeks to contribute a dual outcome: (1) a validated method for energy optimisation in embedded systems, and (2) a pedagogically sound framework for sustainability-focused technical education.

Methodology

This section outlines the methodological framework employed in the development of an IoT lab procedure aimed at optimising power consumption through the use of sleep modes in microcontroller-based systems. The approach integrates both technical experimentation and educational design, grounded in the principles of OBE and aligned with the SDGs, particularly SDG 7 - Affordable and Clean Energy and SDG 12 - Responsible Consumption and Production. The procedure was designed to serve the dual purpose of demonstrating real-time energy

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efficiency techniques while also achieving measurable Course Learning Outcomes (CLOs) within the context of TVET delivery.

The methodology is divided into two main components, as shown in Figure 1. First, the technical experimental setup involved measuring the power consumption of an ESP32-based IoT system operating in various power states: active mode, light sleep, and deep sleep using a current sensor, INA219 and a temperature sensor, DHT11. Data collection was conducted to profile and compare energy usage, providing empirical evidence to support the lab design. Second, the educational development process focused on structuring the laboratory procedure according to Malaysian polytechnic OBE guidelines. This included the formulation of CLOs, mapping to Programme Learning Outcomes (PLOs) and definition of appropriate assessment instruments. The resulting lab module was designed to be reproducible, competency-based, and reflective of real-world engineering challenges faced in energy-constrained IoT deployments.

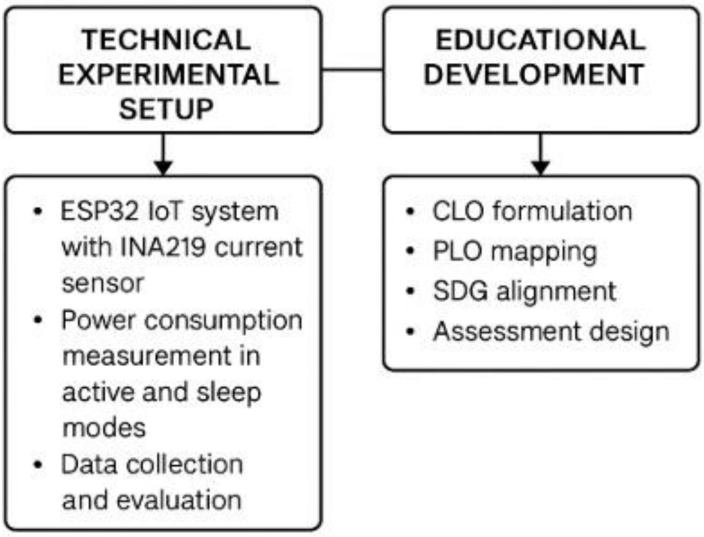

Figure 1: Two components of methodology

Experimental Setup

This experiment consists of two sides, which are the power measurement system and the device under test, as shown in Figure 2.

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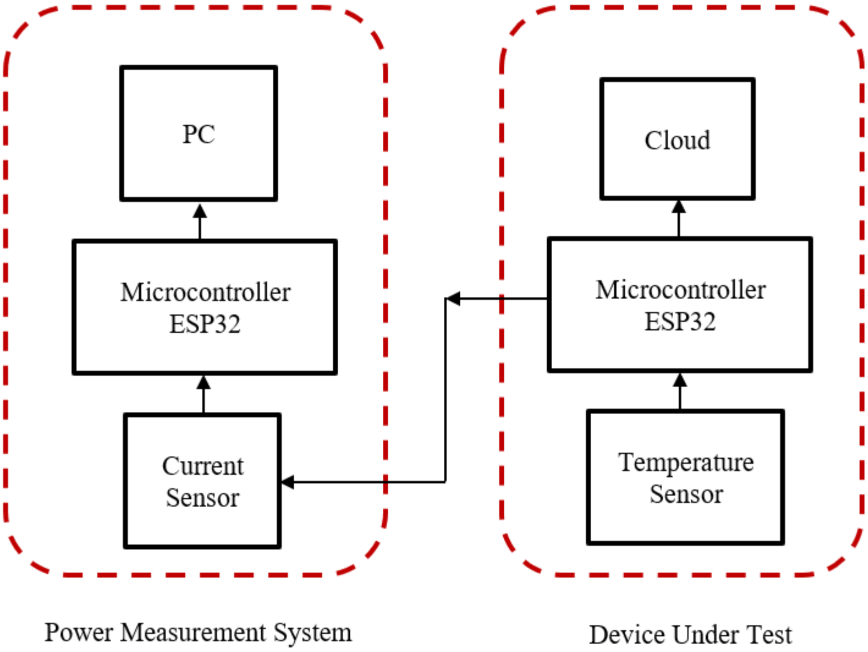

Figure 2: Block diagram of a power measurement system using a current sensor INA219

The power measurement system consists of a microcontroller ESP32 connected to a current sensor, INA219 and a personal computer (PC), while the device under test comprises a microcontroller ESP32 connected to a temperature sensor, DHT11 and the cloud. The details of this setup will be explained using Figure 3.

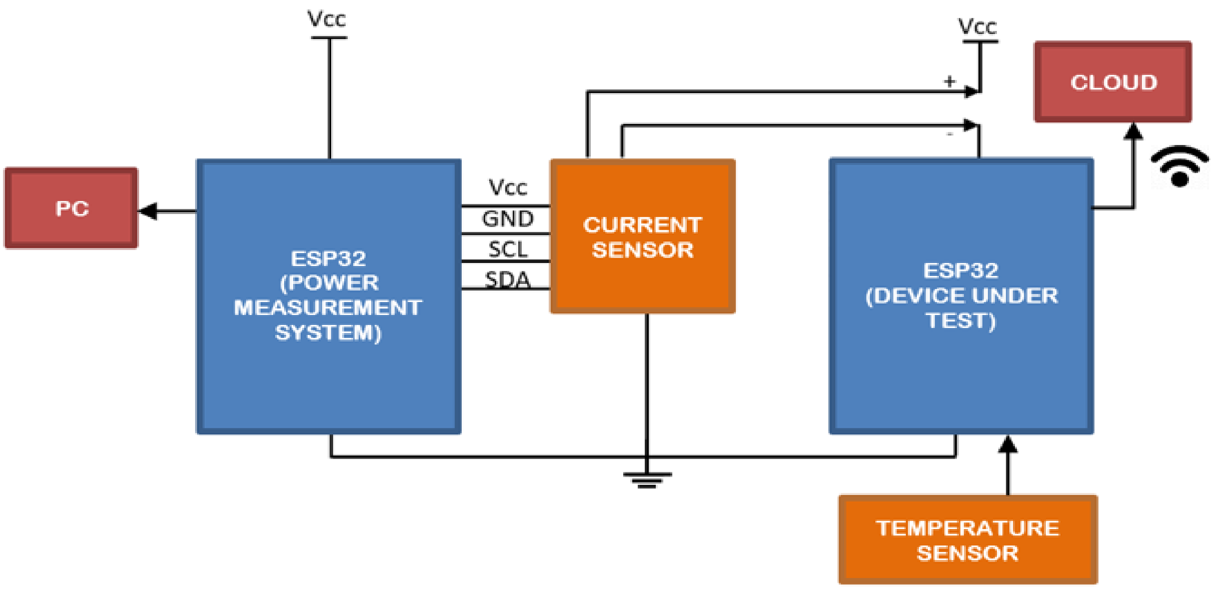

Figure 3: Connection Among Current Sensor, ESP32- Temperature Logger and ESP32-Current Logger.

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Refer to Figure 3, Vcc, GND, SCL, and SDA connections between the ESP32 and INA219 indicate the use of an I2C communication protocol for data exchange. Then, the positive probe and negative probe of the current sensor, INA219, are connected serially between the power supply and the ESP32 to collect recent electrical current in milliampere units from another ESP32 that executes temperature data logging to the cloud through Wi-Fi. This cloud is used for remote monitoring, where data can be accessed and analysed from any location. In this research, Thingspeak is used. At the same time, the current data will be sent to the database in the PC using a USB cable. The measurement system is just like an ammeter. It will measure the current for every experiment, including three power mode situations: unoptimized, deep sleep and light sleep implementation.

Next, the flowcharts of current measurement for three power mode situations: unoptimized, deep sleep and light sleep are explained.

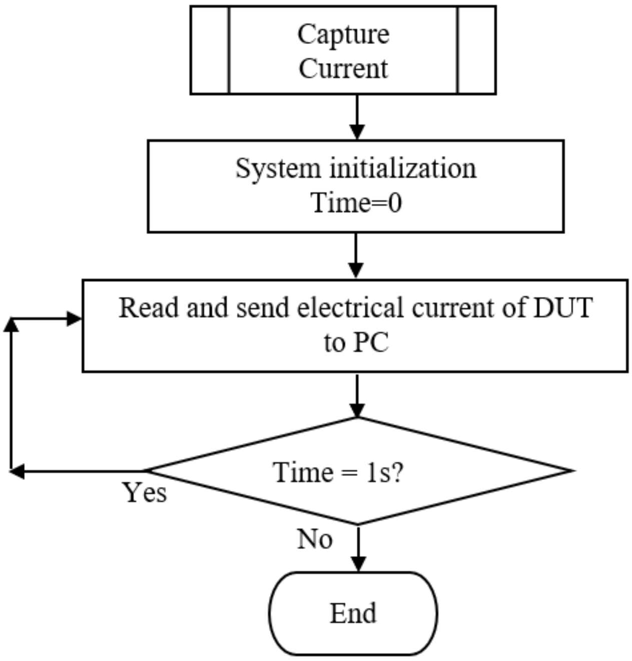

Figure 4: Current Measurement Flow Chart

Figure 4 shows the process of current measurement while the experiment is running. The experiments include an unoptimized system, fixed-scheduled sleep, threshold-based sleep, and an enhanced adaptive sleep strategy. The current and recent time are captured every 1 second and will be sent to a software called PLX-DAQ in a personal computer (PC) as shown in Figure 5. There are many attempts to capture current in other durations, such as 3 seconds, 5 seconds, but there are missing currents when important events occur; the current is not captured. So, 1 second is decided to observe the current without missing any situation, especially the important event, such as when WiFi is turned on and data is being sent.

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Figure 5: PLX DAQ - Excel Interfacing Using USB

After that, energy will be calculated using this formula:

$$E = P \, x \, t$$

where:

$$P = I \, x \, V$$

E is the total energy, P is power, I is current, V is static voltage, 5V and t is time.

Figure 6 shows the flowchart of an unoptimized system with no sleep implementation. This system collects temperature data every 5 minutes and sends it to Thingspeak. The electrical current reading is sent to the PC every second as part of the current measurement flowchart. This is to prepare for data analysis among three strategies: unoptimized, fixed-scheduled sleep and threshold-based adaptive sleep.

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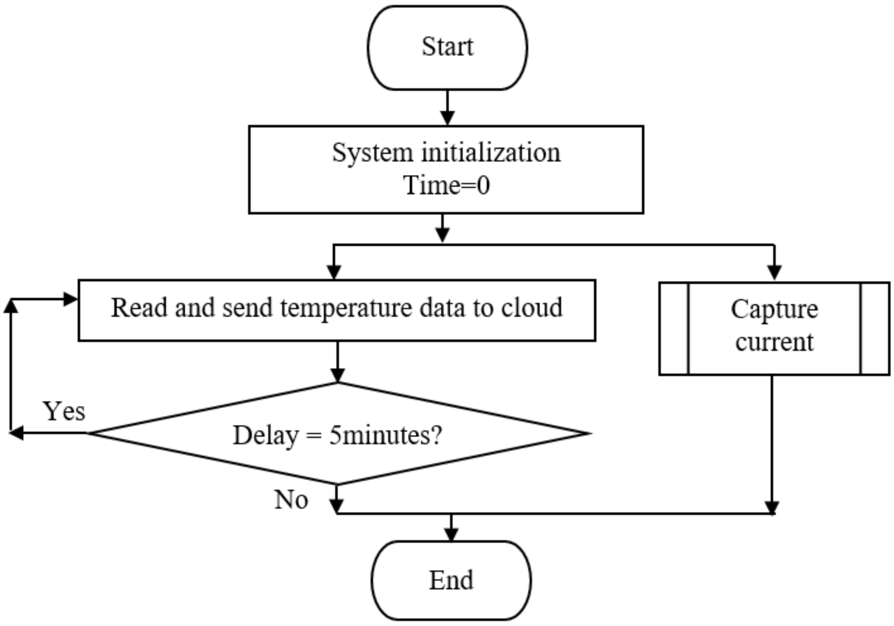

Figure 6: Unoptimized System Flowchart

Refer to Figure 7, the data will be collected and sent to Thingspeak. Then, the system will go to sleep for 5 minutes, which means no data collection, but the electrical current will still be observed.

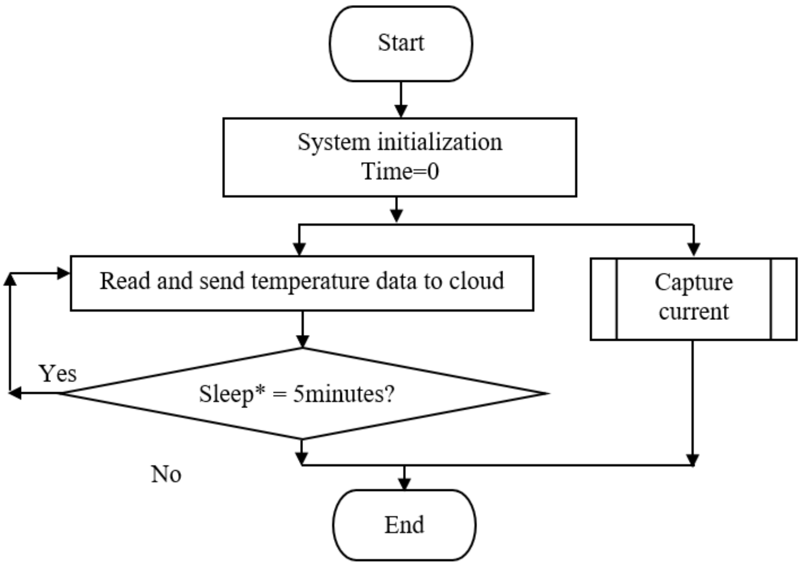

Figure 7: Fix Scheduled Sleep Flowchart (* - This Step Will Be Repeated For Deep Sleep And Light Sleep Implementation)

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Educational Development

OBE framework of Malaysian polytechnics is used to represent TVET institutions and programme learning outcomes, PLO from Diploma in Electronic Engineering (Computer) – DTK, Politeknik Sultan Haji Ahmad Shah (POLISAS) is referred (Politeknik Sultan Haji Ahmad Shah, 2023). Table 1 is designed to align the CLOs with broader PLOs and relevant SDGs, following the OBE framework used in Malaysian polytechnics. Each row in the table links a specific skill or competency (CLO) taught in the lab to a corresponding graduate attribute (PLO), outlines how it will be assessed, and shows how it contributes to sustainability education.

Table 1: CLO–PLO–SDG Mapping for IoT Power Management Lab

Course Learning Outcome (CLO)	Aligned Programme Learning Outcome (PLO)	Assessment Method	Aligned SDG
CLO-1: Demonstrate the architecture and operation of microcontroller-based IoT systems, including sleep mode configurations.	PLO-1: Apply knowledge of applied mathematics, applied science, and engineering fundamentals and an engineering specialisation as specified in DK1 to DK4 respectively to wide practical procedures and practices.	Lab report: system diagrams + sleep mode setup	-
CLO-2: Measure and analyse power consumption of IoT systems in active and sleep modes using appropriate sensors and tools.	PLO-3: Design solutions for well-defined technical problems and assist with the design of systems, components or processes to meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations (DK5).	Data log submission + analysis write-up	SDG 12: Responsible Consumption and Production
CLO-3: Design an energy-efficient IoT prototype that optimizes power consumption using sleep management strategies.	PLO-5: Apply appropriate techniques, resources, and modern engineering and IT tools to well-defined engineering problems, with an awareness of the limitations (DK6).	Prototype demonstration + technical design justification	SDG 7: Affordable and Clean Energy
CLO-4: Reflect on and demonstrate sustainable engineering practices aligned with SDG 7 and SDG 12 in IoT system design. (New CLO)	PLO-7: Understand and evaluate the sustainability and impact of engineering technician work in the solution of well-defined engineering problems in	Sustainability reflection report + rubric-based evaluation	SDG 7 & SDG 12

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	societal and environmental contexts (DK7).

CLOs specify what a student is expected to demonstrate upon completing the lab activities. Each CLO is written to be measurable and specific:

CLO 1: Focuses on understanding and configuring IoT hardware and its sleep modes.
CLO 2: Emphasises the ability to measure and interpret power usage data.
CLO 3: Target design ability in creating an energy-efficient IoT prototype.
CLO 4: Introduces sustainability awareness by reflecting on how their engineering practices relate to environmental impact and SDG goals.

PLOs represent the broader skills and knowledge that students should acquire by the time they graduate. Each CLO is mapped to the PLO that it supports, ensuring constructive alignment between what is taught, assessed, and expected at the program level. These are standardised in Malaysian TVET engineering programs:

PLO 1: Application of foundational knowledge (e.g., circuits, microcontrollers).
PLO 3: Use of tools and analysis to solve engineering problems.
PLO 5: Competency in engineering design using appropriate tools.
PLO 7: Ethics and sustainability in engineering practice.

Table 2 shows the DK Definitions at Politeknik Malaysia. DK refers to the Disciplinary Knowledge categories defined in alignment with the Dublin Accord knowledge profile.

Table 2: DK Definitions at Politeknik Malaysia

DK Code	Definition
DK1	Descriptive, formula-based understanding of natural sciences in the sub-discipline
DK2	Procedural mathematics, numerical analysis, and statistics in the sub-discipline
DK3	Procedural formulation of engineering fundamentals for the sub-discipline
DK4	Specialist engineering knowledge forms the body of the sub-discipline
DK5	Knowledge that underpins engineering design techniques and procedures
DK6	(Repeated) Descriptive, formula-based understanding of natural sciences—or practical engineering knowledge in recognised practice area
DK7	Knowledge of ethical, cultural, financial, environmental, and sustainability dimensions of technical practice
(DK8, DK9)	May include engagement with current technological literature and professional ethics/diversity (context-dependent)

Assessment method details how each CLO will be evaluated. The assessments are practical and performance-based, including:

1. Lab reports and system diagrams (for CLO-1)
2. Power data analysis logs (for CLO-2)
3. Physical prototype development and justification (for CLO-3)
4. Sustainability reflection reports or SDG rubrics (for CLO-4)

This ensures that students are not only gaining knowledge but are also able to demonstrate their skills in meaningful, measurable ways.

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Results And Discussion

Experimental Results

Figure 8 shows the current consumption of an unoptimized system – no sleep. The average of the current is measured for 3600seconds / 1hour. This observation is done for two cycles.

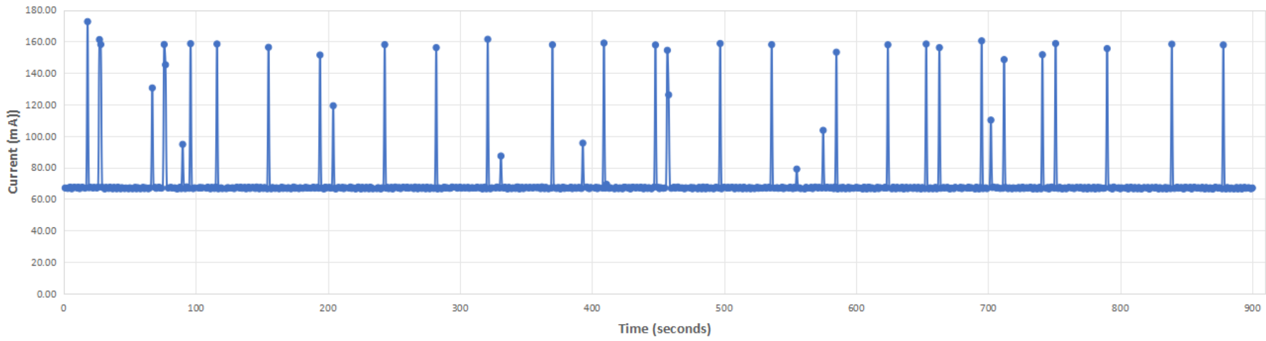

Figure 8: Current Consumption Of The Unoptimized System

Then, power and energy are calculated by multiplying the current by the voltage, which is 5V. The average energy for 3600seconds is 1206.45 Joules, as shown in Table 3.

Table 3: Average Energy Of Unoptimized System – No Sleep

Cycle	Average of Current (A)	Voltage (V)	Power (Watt)	t (s)	Energy (Joule)
1	0.0733	5	0.367	3600	1319.486
2	0.0607	5	0.304	3600	1093.404
				Energy Average:	**1206.445**

Figure 9 shows the current consumption of deep sleep implementation. The average of current is measured for 3600seconds / 1hour. This observation is done for two cycles.

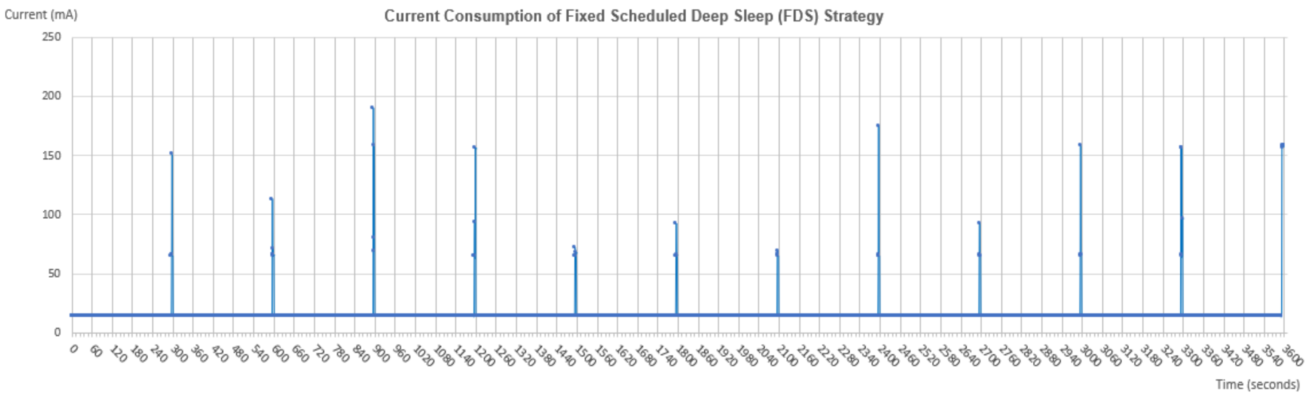

Figure 9: Current Consumption Of Deep Sleep Implementation

Then, power and energy are calculated by multiplying the current by the Voltage = 5V. The average energy for 3600seconds is 283.61 Joules as shown in Table 4.

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Table 4: Average Energy Of Deep Sleep Implementation

Cycle	Current (A)	Voltage (V)	Power (Watt)	t (s)	Energy (Joule)
1	0.0155	5	0.078	3600	279.168
2	0.0160	5	0.080	3600	288.045
	:			ENERGY AVERAGE:	**283.606**

Figure 10 shows the current consumption of the light sleep implementation. The average of the current is measured for 3600 seconds / 1 hour. This observation is done for two cycles.

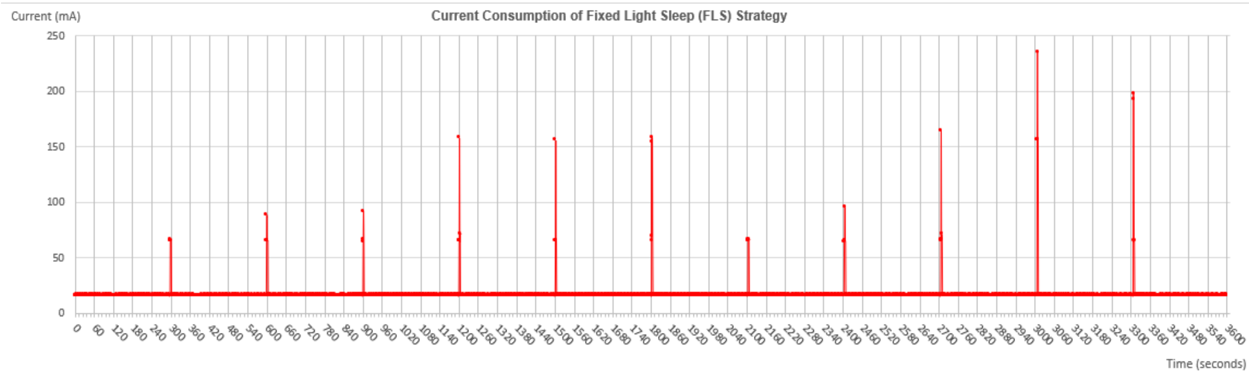

Figure 10: Current Consumption Of Light Sleep Implementation

Then, power and energy are calculated by multiplying the current by the voltage, which is 5V. The average energy for 3600seconds is 318.97 Joules as shown in Table 5.

Table 5: Average Energy Of Light Sleep Implementation

Cycle	Current (A)	Voltage (V)	Power (Watt)	t (s)	Energy (Joule)
1	0.0176	5	0.088	3600	317.125
2	0.0178	5	0.089	3600	320.821
				Energy Average:	**318.973**

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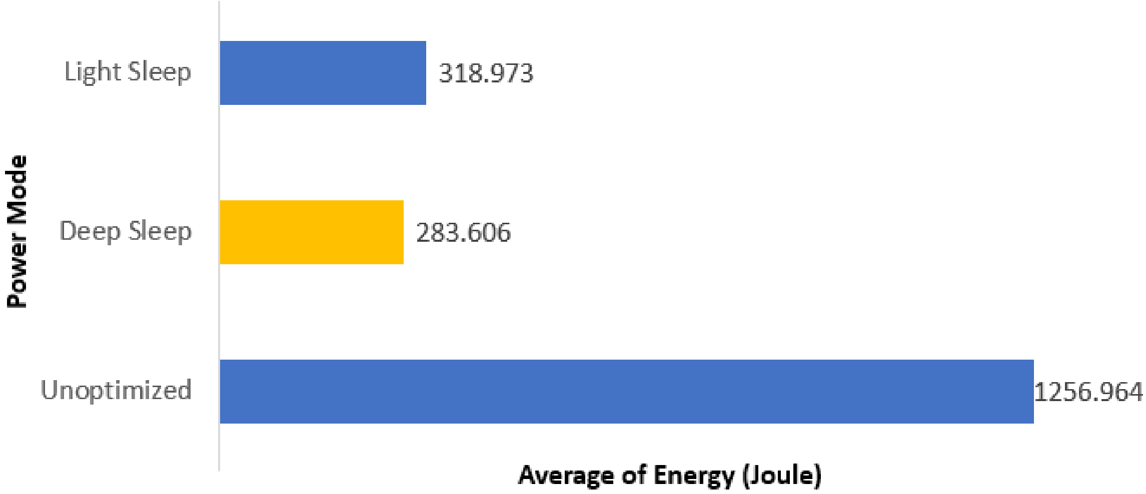

Figure 11: Comparison Of Energy In An Hour For Unoptimized, Deep Sleep And Light Sleep

Figure 11 shows the comparison among unoptimized, deep sleep and light sleep. An unoptimized system with no sleep implementation consumes the highest current, which is 1256.96 mA, compared to a fixed scheduled deep sleep and a fixed scheduled light sleep. Furthermore, fixing scheduled deep sleep saves the highest energy, 77.44%, and is followed by light sleep, 74.62%, compared to an unoptimized system.

These results show that sleep mode can save more energy, using only a simple lab procedure to highlight the benefits of sleep mode features in the microcontroller. Furthermore, there are no additional costs to incorporate this lab procedure to achieve the CLO, PLO, and SDG.

Proposed Lab Procedure

Learning Objectives and CLO Integration

The lab activities are mapped to four Course Learning Outcomes (CLOs), covering:

1. Understanding IoT hardware architecture and sleep mode configuration.
2. Measuring and analysing power consumption using INA219 or equivalent sensors.
3. Designing an energy-efficient IoT prototype through optimised sleep strategies.
4. Reflecting on sustainable engineering practices and their alignment with SDG goals.

This alignment ensures that students not only acquire technical skills but also develop environmental and ethical awareness.

Required Equipment and Tools

1. Hardware: ESP32 development board, INA219 current sensor, DHT11 temperature sensor, breadboard, jumper wires, USB wire
2. Software: Arduino IDE, PLX-DAQ, Thingspeak

Step-by-Step Lab Activities

1. Setup and Configuration: Connect the ESP32 to the INA219 and DHT11 sensors according to the wiring diagram. Install necessary Arduino libraries.

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2. Active Mode Testing: Program the device to read temperature, send data via Wi-Fi, and remain active. Record current and voltage data for a fixed interval.
3. Light Sleep Testing: Modify the code to implement Light Sleep Mode between transmissions. Measure and log power consumption data.
4. Deep Sleep Testing: Implement Deep Sleep Mode with timed wake-up. Record and compare power usage against previous modes.
5. Data Analysis: Calculate average current, voltage, and power for each mode. Determine percentage savings compared to Active Mode.
6. Reflection and SDG Alignment: Students prepare a short report discussing results, implications for IoT device design, and connections to SDG 7 and SDG 12.

Assessment Strategy

1. Technical Competence (CLO 1–3): Assessed via lab reports, data accuracy, and functional prototype demonstration.
2. Sustainability Reflection (CLO 4): Assessed via a written reflection linked to sustainability rubrics.
3. Practical Skills: Observed during lab sessions, with emphasis on problem-solving, troubleshooting, and teamwork

Conclusion

This paper presented the development of a structured laboratory procedure for teaching IoT power management using sleep modes in microcontroller-based systems, designed specifically for implementation in Malaysian polytechnics and other TVET environments. By combining empirical experimentation with educational design principles, the proposed framework bridges the gap between technical skill acquisition and sustainable engineering practices. Experimental results using an ESP32 microcontroller and INA219 current sensor clearly demonstrated the substantial reduction in power consumption achieved through Light Sleep and Deep Sleep modes, providing a robust technical foundation for student learning activities.

The lab procedure was constructed within the Outcome-Based Education (OBE) framework, ensuring that each Course Learning Outcome (CLO) was constructively aligned with relevant Programme Learning Outcomes (PLOs) and explicitly linked to the United Nations Sustainable Development Goals (SDG 7: Affordable and Clean Energy and SDG 12: Responsible Consumption and Production). This integration not only equips students with hands-on competencies in energy-efficient IoT design but also fosters environmental responsibility and ethical awareness key attributes for future-ready engineering graduates.

The proposed lab is designed to be reproducible, scalable, and adaptable across various TVET institutions, making it a viable model for embedding sustainability-driven technical education into IoT and embedded systems curricula. Future work will focus on implementing the lab in classroom settings, evaluating its impact on student performance and sustainability awareness, and expanding its scope to include advanced energy optimisation techniques such as duty cycling and edge-based machine learning.

While the proposed lab procedure successfully integrates technical experimentation with OBE-based curriculum design, several areas can be explored to enhance its educational and practical impact. First, future work should involve pilot implementation across multiple Malaysian polytechnics and TVET institutions, followed by evaluation of student learning outcomes,

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sustainability awareness, and technical skill acquisition. This will provide quantitative evidence of the lab's pedagogical effectiveness and inform iterative improvements.

Second, the integration of real-world case studies and industry collaboration is recommended, enabling students to relate laboratory exercises to authentic IoT deployment scenarios in sectors like smart agriculture, environmental monitoring, and industrial automation. Partnerships with industry could also facilitate access to diverse hardware platforms and professional feedback on student projects. Embedding these enhancements into the lab framework would not only deepen technical competencies but also reinforce the sustainable engineering practices needed to address global challenges, in alignment with SDG 7 and SDG 12.

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