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Article

AI Based Smart Energy Saving and Consumption Management for Industries

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Abstract

This paper introduces an intelligent energy management system (EMS) designed to enhance energy efficiency in office, academic, and industrial environments through real-time human presence detection and IoT-based monitoring. Unlike conventional motion sensors, the proposed system employs image processing and machine learning algorithms implemented on a Raspberry Pi platform to accurately and contactless identify occupants. Based on detected occupancy, the system dynamically controls connected electrical loads via Arduino-based relays, minimizing unnecessary power usage and improving operational efficiency. In parallel, a real-time three-phase monitoring module was developed using PZEM-004T sensors and ESP8266 microcontrollers to measure voltage, current, and power factor across industrial networks. The data is processed locally and uploaded to a cloud dashboard for visualization, fault detection, and maintenance planning. Experimental validation demonstrates that both systems operate reliably under varying load conditions and significantly reduce energy wastage. The proposed dual-module approach—combining intelligent occupancy-based control with IoT-enabled monitoring—provides a cost-effective, scalable, and practical solution for modern energy management. It not only improves efficiency and safety but also establishes a foundation for future integration with renewable energy systems, predictive analytics, and privacy-aware smart building architectures aimed at promoting sustainability in industrial and institutional settings.

Keywords: Energy efficiency, energy saving, occupancy detection, Raspberry Pi, image processing, real-time monitoring.

1. Introduction

In recent decades, the exponential growth in energy demand, coupled with increasing concerns over environmental sustainability, has intensified the focus on efficient energy management systems—particularly within industrial and office environments. Traditionally, energy conservation in these sectors has relied on passive technologies such as motion sensors, time-controlled switches, and programmable logic controllers. Although these devices offer a degree of automation, they remain fundamentally limited in granularity and responsiveness. Motion detectors, for example, typically offer binary input (motion/no motion), lacking the ability to determine precise occupancy metrics such as the number, identity, or activity level of individuals within a space.

Furthermore, conventional systems often leave lighting and HVAC units operational in unoccupied zones, contributing to unnecessary power consumption, elevated operational costs, and increased carbon emissions. With the advent of the Internet of Things (IoT), there has been a paradigm shift towards more dynamic, data-driven solutions. IoT-integrated frameworks now allow for remote monitoring and control of energy systems. However, even with such advancements, many commercial and industrial setups still fall short of implementing truly "smart" energy solutions—ones that combine real-time decision-making, human-context awareness, and operational safety

This research aims to design and evaluate a smart energy management system (SEMS) that leverages real-time image processing and IoT capabilities to optimize energy consumption in industrial settings. Specifically, the system integrates:

Human presence detection using Raspberry Pi and camera modules, enabling more accurate and contactless occupancy recognition compared to traditional motion sensors.

Dynamic load control mechanisms that respond in real-time to occupancy data to manage electrical loads such as lighting and HVAC.

IoT-based three-phase power monitoring for industrial safety, load balancing, and energy efficiency tracking.

While existing energy management systems offer partial automation and monitoring capabilities, they are typically constrained by:

Low-resolution detection methods that rely on IR or ultrasonic sensors can be unreliable in complex spatial environments.

Inflexible automation rules, which do not adapt well to real-time human behavior or occupancy variance.

Limited real-time visibility into power distribution across three-phase systems hampers rapid fault detection and load optimization.

This paper addresses this gap by proposing a novel SEMS architecture that bridges the limitations of traditional systems, validated through practical implementation and experimental testing in industrial environments.

In contrast, natural fibres like human hair are renewable, biodegradable, and require minimal processing, making them a more sustainable option. The use of human hair as a reinforcement material in concrete has several potential advantages. Firstly, human hair is a waste product that is readily available in large quantities, particularly in urban areas. Secondly, the concern for energy conservation and preservation has boosted lots of interest towards finding efficient measures of electrical energy utilization in different sectors, such as business premises, learning institutions, as well as in sophisticated technological industries. One has to mention load control in commercial office buildings as one of the main areas of interest, as energy efficiency and conservation are achieved through load control and change management. Literature in this area has revealed that these interventions, albeit often resulting in a positive Net Present Value, are questionable in terms of the returns on the initial investment. But other related improvements in the workplace that may include enhanced worker productivity and satisfaction may warrant the extra costs from a project management perspective. As noted, energy efficiency is also an issue of concern in other institutions such as universities. One relevant study conducted at University Tun Hussein Onn Malaysia (UTHM) is a research on the energy consumption behavior of a university library. This research indicates a number of technical steps, such as the replacement of light types, the installation of sensors, the reduction of the number of lamps, as well as the improvement of the shading coefficient, which, in turn, produce considerable results in the sphere of energy saving [1]. Another important fact stated in the study is that 10 % of energy savings result from a change in human behaviour, while the remaining 90% arises from technological factors, underlining the need to design an integrated approach to energy efficiency. Along with these classical approaches, the availability of new powerful machine learning algorithms opens new opportunities in the case of continuous identification of people, which considerably improves the occupancy-based energy management systems.

The application of these strategies is shown by research on the implementation of deep learning to embedded devices, including the Raspberry Pi and NVIDIA Jetson [2-4]. This finding opens up potential for energy management systems that, based on current occupant density, efficiently distribute energy. Based on these results, we proposed the picture analysis in combination with real-time people detection for upgrading an occupancy-based energy control system. This strategy is aimed at sensitively detecting human presence through the installation of cameras and the use of machine learning algorithms, possibly using Raspberry Pi devices [5-8]. This information can then be transferred straight into commands for energy-using systems in different rooms of the building, therefore saving energy when it is not needed by using an optimal program. This paper is not only beneficial in illuminating the positive possibilities of current energy management methods, as well as the issues that can be associated with those approaches, but also provides the foundation for entirely new ideas that apply modernity to increase the effectiveness and efficiency of energy usage.

An exponential interest has been given, thus, on the requirement of real-time monitoring of three-phase power structures. Initially, less attention was paid to the methods of manual and periodic monitoring, and while they were deemed sufficient to meet the requirements of industries of the past, they proved insufficient in the industrial environments of the present [6]. Due to the progression in the use of digital electronics and microprocessors, automated monitoring systems have evolved, but they are not real-time based and as such cannot support real-time monitoring and immediate corrective measures.

There have been emerging research studies which show how IoT and cloud computing can serve as a solution to power system monitoring [2]. However, there are issues that need to be addressed, such as data accuracy, data integrity, secure data transfer, and interconnectivity with the existing systems, among others. These challenges are made worse by the sheer volume of data being generated in today's world and the necessity for handling solutions at a large scale.

2. Identifying Research Gaps and Proposing Solutions

Every so often, strategies have been developed to enhance the occupancy-based energy control systems in commercial, institutional and residential facilities. The first and arguably the least expensive technique involves applying infrared (IR) sensors to capture the mobility under the utilization of heat from the body. They are cheap and easy to fit as compared to the other sensors. However, their effectiveness is somehow reduced given the fact that they are not capable of differentiating between the human and non-human heat sources; their performance may also be easily impacted by factors such as temperature and air circulation. Another widely used type is ultrasonic sensors that utilize ultrasonic waves emitted and received in order to sense motion. Even though these sensors may operate in numerous environmental situations and may detect an even larger space as compared to the IR sensors, their restrictions are similar. Specifically, they fail to differentiate between human and any other forms of movement and, therefore, are not very accurate. Also, since the technological market can be fragile to outside influences like noise and certain forms of physical barriers, it can also be unreliable. Smart thermostats and environmental sensors present a more complicated way of evaluating occupancy by analyzing other environmental factors like warmth, humidity, and the amount of CO_2. The following gadgets provide the requisite information while altering HVAC systems. But they do not provide real-time occupancy information and are often based on patterns and assumptions that are far from the actual ones, thereby being inefficient. Bluetooth and Wi-Fi-based systems detect occupancy by identifying the presence of smartphones and other gadgets. Thus, these systems can offer quite reliable information in situations where the user constantly interacts with electronic devices, but it highly depends on the engagement of the user and the availability of personal electronic devices. This dependence on the user behaviour is its biggest strength as well as weakness, making it unpredictable and may not be suitable in many settings where the use of the device is irregular or prohibited.

The proposed works resolve these gaps by implementing real-time human detection based on image processing and machine learning. Much accuracy is made possible by using particular cameras and machine learning models that are run on specific platforms such as Raspberry Pi. It is thereby more reliable in many circumstances as compared to the IR as well as the ultrasonic sensors because it is less sensitive to the environmental status. Thus, by satisfying these specific gaps, the suggested method enhances not only the occupancy detection but also the efficiency of EMS as a whole. Through the incorporation of new innovations, the cost of operation is reduced, and more importantly, there is a gain in efficiency in energy usage in commercial, institutional and residential buildings.

Specifically, as it has been established that while there are many options with regard to monitoring solutions, they still lack fully integrated, real-time monitoring systems that utilize the best of the current IoT and cloud technologies. Currently available solutions do not possess the ability to solve problems in real-time, thus it is difficult to apply them in the fight against time-consuming and production-halting scenarios. Most current systems cannot cope with the increasing data amounts and the increasing size of industrial processes. Compatibility with industrial systems and processes continues to be an issue, which will need enhancement and investments. It means that today, there are requirements for not only a tool that will help diagnose problems, but also a tool that will allow foreseeing possible problems and perform planned, advanced preparation.

In order to fill these gaps, the authors suggest using the concept of smart monitoring, which involves the use of various sensors, the Internet of Things, and cloud technology. The elements of this solution are the installation of highly accurate sensors at specific phases that measure the voltage, current, and power factor. These sensors will provide real, accurate information for collection since the evaluation of life is a sensitive process. A strong data acquisition section that gathers real-time data from the sensor and ensures the data quality before sending it over secure links to the cloud. Harnessing the power of cloud solutions as the data repository and the solution for real-time, big data analyses. This will lead to the generation of patterns and analyses that can help in the detection of probable emergent abnormality. Some are: Creation of an easy-to-use interface where the data is displayed in the form of dashboards and where alerts are given to maintenance teams for immediate recommended action. Real-time data analysis and predictive maintenance algorithms that help identify future problems that exist and raise the alarm to avoid big losses in the form of many days of downtime. This proposed solution is expected to improve the present monitoring system's functionality, minimize risks, and significantly reduce costs to make the workplace safer and more efficient based on the gaps indicated in the research.

3. Methodology

3.1. Single Phase Load Control Based on Image Processing:

The need for the research we conducted came from a pressing need to address the inefficiencies inherent in existing load management systems, which frequently result in wasteful energy use and insufficient resource utilization. For that, we are installing a prototype of our project in our university lab. Conventional systems do not react dynamically to shifting occupancy patterns, resulting in energy waste and higher operational expenses. To address these issues, we worked to create a complex system capable of automatically controlling electrical loads using real-time occupancy data, thereby optimizing energy consumption and improving user experience. Our approach is built on the creation of a machine learning algorithm designed specifically for human detection. Drawing on a wide dataset, our method uses advanced image processing techniques to reliably detect the presence of persons in the lab environment. By analyzing visual patterns such as body forms, particularly the head, the system creates exact signals identifying the position and quantity of observed humans, resulting in occupancy-based load control. This system will be smart enough to detect the location of a person in the room, making it easy for Arduino to switch loads on given input from the Raspberry Pi as shown in Fig. 1.

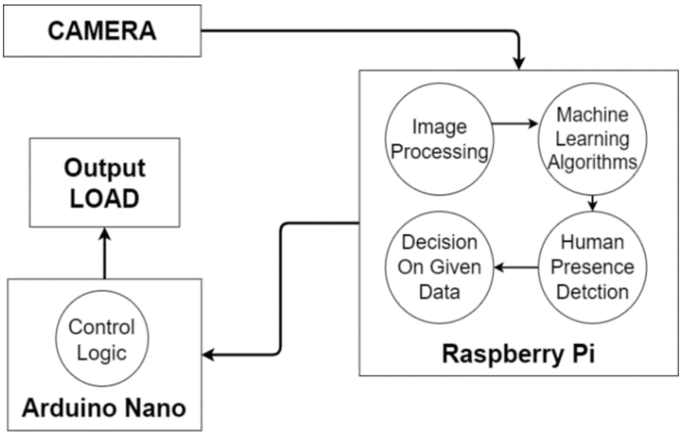

Figure 1. Block Diagram of Single-Phase Load Control

Our system has been designed to allow for smooth interaction between hardware components and software modules shown in Fig. 2. The integration of a Pi Camera with a Raspberry Pi is important to this system, since it provides extensive coverage of the lab environment. The Pi Camera shown in Fig. 3 continually takes high-resolution photos, which are then sent to the Raspberry Pi for real-time processing. The Raspberry Pi acts as the central processing unit, managing the execution of the machine learning algorithm and allowing connection with the Arduino Nano microcontroller.

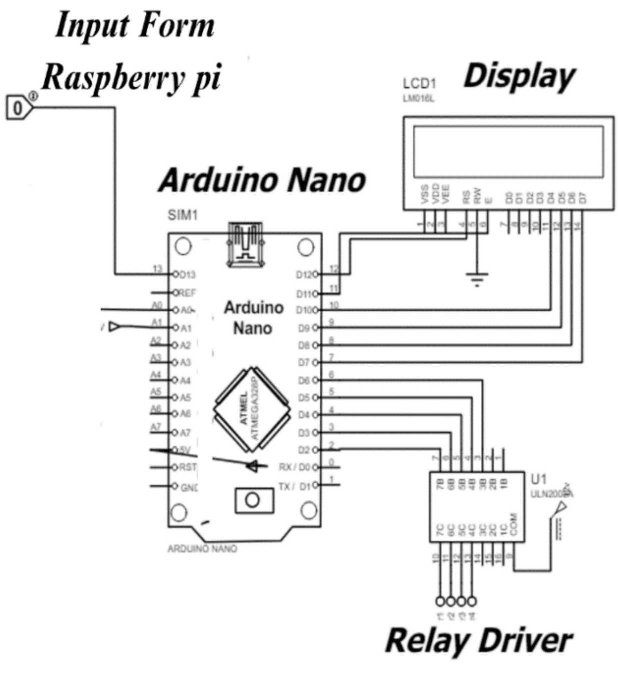

Figure 2. Schematic of Arduino, Display, Relay and Input

The method we use is distinguished by an innovative notion of occupancy-based load management, which activates and deactivates electrical loads dynamically in response to recognized human presence within the lab area. When the Arduino Nano microcontroller receives signals from the Raspberry Pi showing the presence and position of persons, it executes load control commands, selectively activating only the loads closest to the observed humans. This narrowed strategy reduces energy waste and optimizes utilization of resources, improving overall system efficiency.

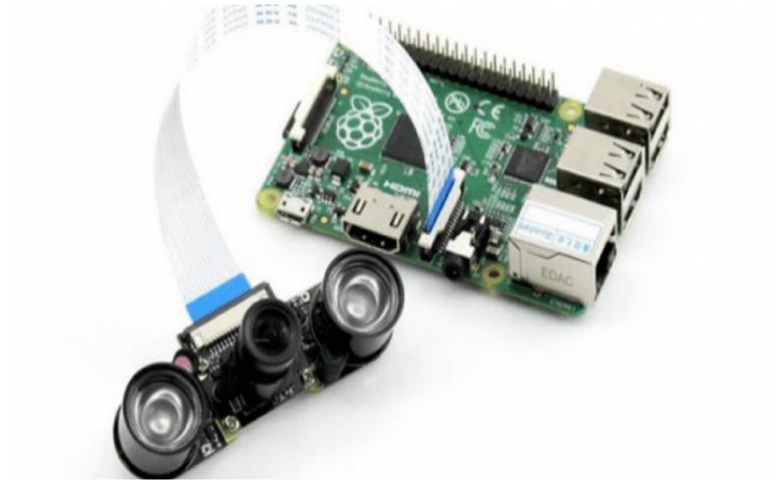

Figure 3. Raspberry Pi With Cam

To improve system performance even more, we've included a seasonal changeover mechanism that adjusts load configurations based on current weather conditions. During the winter, users can shift the changeover to winter activities, which activate winter-related loads such as lights, but in the summer, all summer-related loads, including fans, air conditioners, and lights, are activated to ensure ideal convenience. Furthermore, our method of operation supports both automated and manual control modes, allowing customers to personalize load activation to their own personal preferences and circumstances shown in Fig. 4.

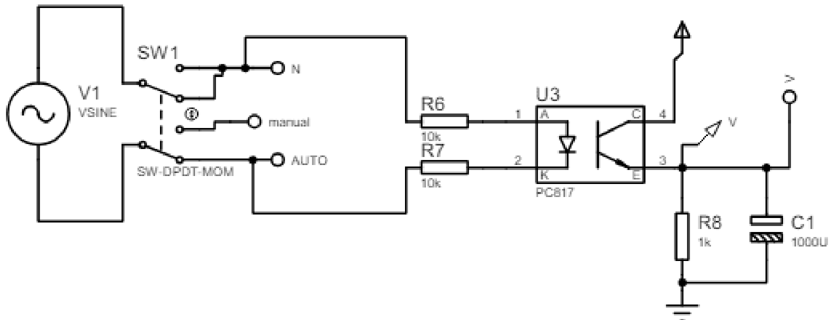

Figure 4. Schematic of Change Over

3.2. Real Time Three Phase Power Supply Measurement:.

The following steps are important in the process of putting in place this real-time monitoring system. The first step is basic, the Sensor Deployment, which means that advanced high-precision sensors will be placed in our device, and then the device will be set on the power distribution network. These sensors are chosen based on their Metrologic performance and ability to withstand adverse conditions characteristic of industries, therefore enabling accurate voltage, current and power factors' measurement for each phase. The next phase after the deployment of the Data Acquisition. This unit is first in charge of bringing together the data feed and performing initial preparatory steps in order to eliminate entries that are not of interest, as well as making sure that the data feed is clean. This means that the quality of the collected data will be accurate and reliable for the next steps of the analysis. However, to apply the described algorithms to the data, it must be transferred to the cloud after it is gathered. This step, Data Transmission, entails the DAU making the processed data available to a cloud-based platform via secure channels. Real-time transmission is also useful in ensuring that the monitoring system wastes no time and gets the latest information available.

In the Cloud Computing phase, the transmitted data is saved, and the computation is done with the help of a huge number of actual computing resources. Real-time data processing will be performed on the cloud platform, which will include fundamental analytics algorithms to identify patterns which may lead to decision-making shown in Fig. 5. This step harnesses the power of cloud computing, including scalability to deal with large volumes of data. Data Analytics is the process of analyzing the processed data so as to independently draw the patterns, vices and even probable defects. The analytical information and diagnostic solutions that are to be derived from computer processing will incorporate the use of such tools as machine learning algorithms, for example, for predictive maintenance. This step helps the system be able to prevent issues before they result in major complications. In order to make the collected data handy, a User Interface is to be created. This is, in fact, a dashboard that will show data and statistics in a graphical format as the actual data are received, the trends, and if necessary, the alerts for the given data. It will be built to be extremely easy to use so that maintainers have an easy time keeping abreast with the system and fixing any problems that may arise. The interface itself will operate on the Web and the mobile platforms, so users will be able to get to the needed information easily.

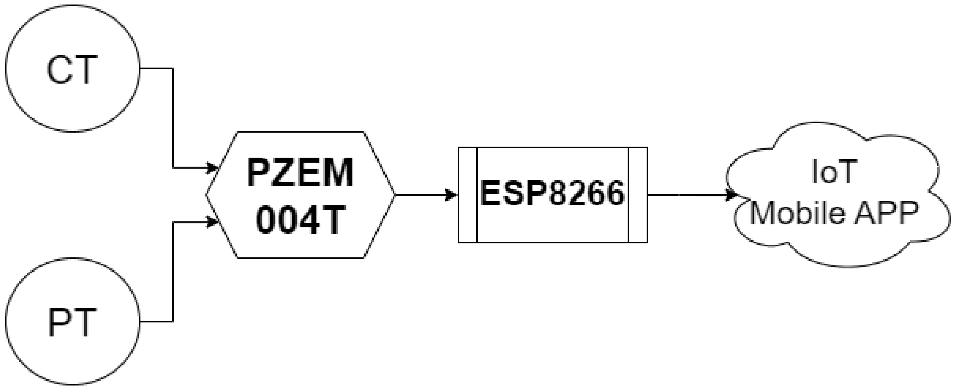

Figure 5. Block Diagram of the Working of Real-Time Three-Phase Power Measurement

3.3. Prototype Development And Testing

In the development of our hardware design and implementation, all the processes from the development of simulations, creation of a working device, design of an AI model, circuit testing using Proteus, building the physical circuit components and coding in the Arduino software development environment is involved. Due to the nature of the required functionality, the main purpose of the prototype is to have an adaptive environment switch based on the current occupancy in order to minimize energy usage of electrical loads.

3.3. Prototype Development And Testing

3.3.1 Development of Ml Model:

The improvement of the occupancy-based load control system through the implementation of the MobileNet model, which is trained with machine learning and tangible automation systems. It begins with the choice of the MobileNet model, which proved to be effective for image recognition and suitable for utilization in embedded devices because of its compactness. As a preliminary step for further exploitation of the characteristics of the model, it was trained with a specialized dataset for human detection. This extensive training phase was a critical training process for developing the model's ability to distinguish the presence of people correctly and consistently, regardless of situations and conditions.

The next action carried out was the merging of the completed updated model to a Python-based framework specifically designed for real-time picture processing [9-11]. The system was made to be highly sensitive with the capability of comprehending geographic information before swiftly arriving at a decision concerning load management. For instance, if a person walks into a room, the system switches on the light when the person is in the room to ensure comfort; or adjusts the heating/cooling system to ensure the comfort of the person in the room, and switches off the light or the heater/cooler when the room is empty so as to conserve energy. These tests were conducted to ensure that the system was efficient and effective in performing its functions, see Figs. 6, 7 and 8. This includes programming various occupancy schemes and assessing the system's response to confirm it could detect presence and adapt loads properly.

Figure 6. Person Detection (LEFT)

Figure 7. Person Detection (RIGHT)

Figure 8. Person Detection (LEFT & RIGHT)

3.3.2 Development of Single Phase Load Control based on Image Processing :

For circuit simulation of our project we used Proteus software, a versatile software that can simulate electrical circuits before circuit board implementation. During this simulation phase, instead of the actual input from the Raspberry Pi that would normally be incorporated into the system, a binary input was used for system behavior validation. This substitution gives us an idea of the system response based on the simulation of occupancy signals, thus easing the simulation exercise. By doing this we can easily give our Arduino High and Low signal and check about working of our other components. After integration of image processing in raspberry pi, we will able to get this input automatically.

After successful validation through simulation, we proceeded to the hardware assembly phase, which involved integrating the components into a functional prototype. The Pi Camera is rightly placed to record the entire region. It always takes pictures and sends such images to the Raspberry Pi, where they will be processed. An algorithm for machine learning is implemented on the Raspberry Pi to identify people and their area of presence. The control signals from the Raspberry Pi are then transmitted to the Arduino Nano, which performs the control logic to switch on/off the relays and the magnetic contactors. It gathers occupancy information from the Raspberry Pi and regulates current electrical demands.

Relays and Magnetic Contactors are connected with the Arduino Nano for switching of electrical loads. For the lighting and fans, the relays are applied, and for the air conditioning systems, magnetic contactors are used. A changeover switch can be used to choose the current season, such as winter or summer, and the control mode, either automatic or manual. Occupancy data and aspects related to the season determine the performance of the system when it is in the automatic mode. When the usage is in manual mode, users can individually manage the loads. The LCD display is connected to the Arduino Nano, and it shows a summary of the status of the mode, time, and load that is currently active.

The control logic was typed and later programmed in the Arduino IDE and then flashed onto the Arduino Nano. Thus, this code will make a decision on its input from Raspberry Pi signals relating to the presence and position of people. Depending on these signals and season settings, the Arduino Nano turns on the right load or switches off the undesired ones. For instance, if human beings are observed on the left part of the lab, only the left side load is brought into operation. When there are people on both sides, both units of loads are switched on. There are added options for toggling between automatic and manual modes of the device. Thus, in the fully automatically operated mode, the loads are regulated in response to occupancy and seasonal factors. In the manual point, we have the option to override the automatic controls deliberately by the users. The Arduino Nano synchronizes the data for updating the LCD screen, thus providing the users with the system operational details shown in Fig. 9.

Figure 9. Hardware Testing 1

3.3.3 Development of Single Phase Load Control based on Image Processing :

Connect the input terminals of the PZEM-004T module to the power lines using appropriate wiring. Ensure that the wiring connections are secure and insulated to prevent electrical hazards. Set the address and communication parameters of the PZEM-004T module, if necessary, using the provided documentation or configuration tools. Verify that the module is correctly configured and ready to communicate with other components. Identify the appropriate pins on the ESP8266 D1 R2 Mini for connecting the OLED display. Typically, these pins include SDA (data line) aand SCL (clock line) for I2C communication. Use jumper wires to connect the SDA and SCL pins of the OLED display to the corresponding pins on the ESP8266 D1 R2 Mini. Connect the power (VCC) and ground (GND) pins of the OLED display to the 5V and ground pins, respectively, on the ESP8266 D1 R2 Mini. Ensure that the power connections are secure and provide stable voltage to the OLED display.

Connect the ESP8266 D1 R2 Mini to a computer using a USB cable for programming. Install the necessary drivers and development environment (e.g., Arduino IDE) on the computer. Load the firmware or code onto the ESP8266 D1 R2 Mini using the Arduino IDE or other programming tools. Write code to interface with the PZEM-004T module and the OLED display, reading data from the module and displaying it on the OLED display [11]. Connect the HiLink 5V power supply to a stable AC power source. Use a USB cable to connect the output of the HiLink power supply to the micro USB port on the ESP8266 D1 R2 Mini. Ensure that the power connection provides stable voltage to the ESP8266 D1 R2 Mini for proper operation. Connect the HiLink 5V power supply to a stable AC power source using a standard power cord. Ensure that the power source meets the voltage and frequency requirements of the HiLink power supply. Connect the output terminals of the HiLink 5V power supply to the micro USB port on the ESP8266 D1 R2 Mini. Verify that the output voltage is stable and within the operating range of the ESP8266 D1 R2 Mini. Power on the HiLink 5V power supply and verify that the output voltage is correct. Ensure that the power supply is functioning properly and providing stable power to the ESP8266 D1 R2 Mini and other connected components (see Fig. 10).

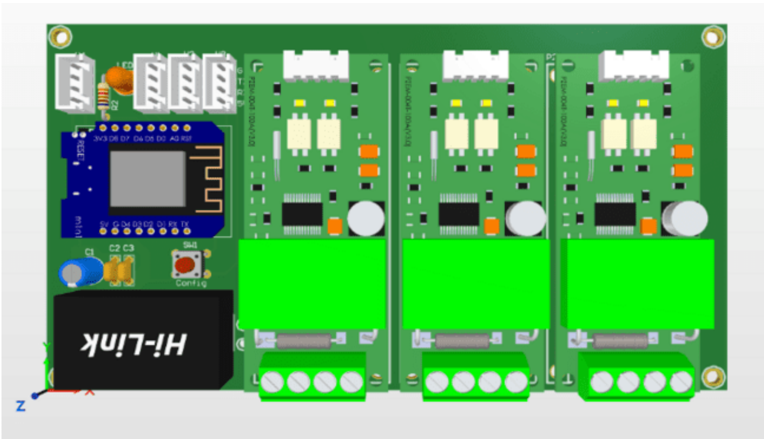

Figure 10. 3D Model of Power Measurement Device

3.3.3 Testing of Hardware in Loop:

Finally, for every hardware used in the project, and every line of control code written, it was incorporated into constructing the final project. They were applied to the implementation to execute the human detection algorithm and supply the occupancy status to the Arduino Nano. The Arduino Nano, on the other hand, controlled the relays and the magnetic contactors, hence acting as a means of regulating the electrical loads. The various tests were conducted to the greatest degree as required to meet the initial goal of the system. This also entailed testing of several occupancy profiles, making certain that the relays and contactors are working appropriately, hence confirming that the switch between the seasonal settings and the controlling modes is correctly done as required.

Evaluating is an essential process in the development of the real-time monitoring system of three-phase power supplies. It entails testing the hardware and software in order to satisfy oneself that they would perform as expected when integrated into the system. Listed below are the series of tests in this testing process: The component level test to ensure that each component truly works as it should by testing the PZEM-004T sensors, OLED display, ESP8266 D1 R2 Mini, and HiLink 5V power supply (see Fig. 11). Acceptance testing is done after the different individual components are tested, and then integration is done to make sure that everything fits as expected. This includes checking of the sensors, microcontroller and the display's ability to communicate with one another, stability of the power source and the precision of the data transmitted.

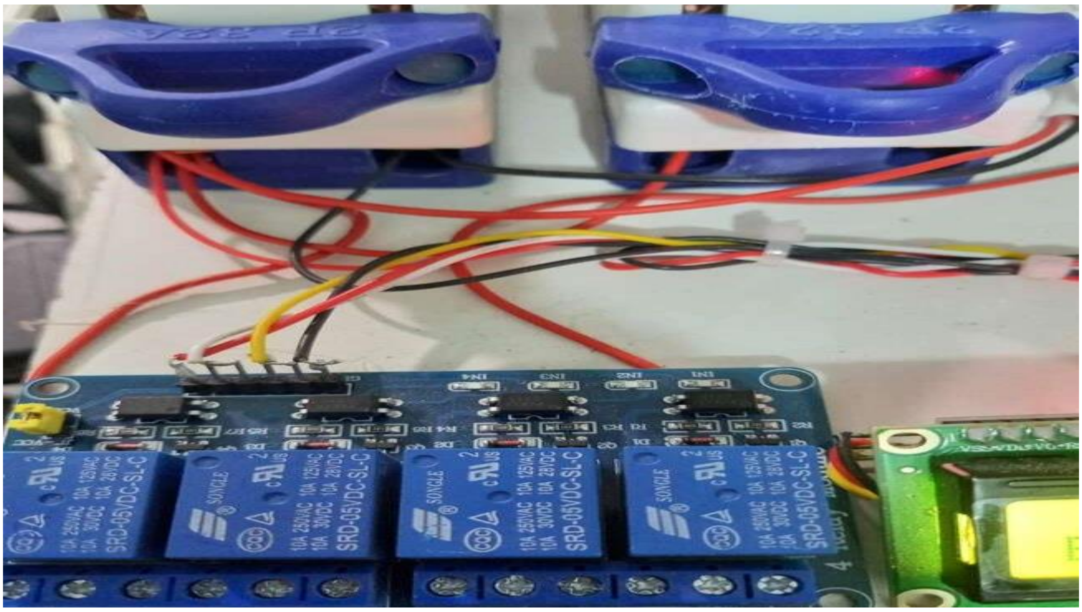

Figure 11. Hardware Testing-2

4. Conclusion

This work successfully developed two practical solutions for smarter energy management. First, an intelligent occupancy-based load management system was implemented using machine learning with Raspberry Pi, Arduino Nano, and relays. The system accurately detected occupancy in a university lab, dynamically controlled loads, and reduced energy waste. Key strengths include improved efficiency, user-friendly control modes, and potential scalability. Challenges such as hardware complexity, cost, and privacy must be addressed for broader adoption. Future work can explore integration with renewable energy sources and enhanced privacy measures.

Second, a real-time monitoring system for three-phase power supplies was designed using PZEM-004T sensors, ESP8266 microcontrollers, and IoT integration. The system reliably tracked voltage, current, and power factor, enabling early anomaly detection and proactive maintenance. Features like the OLED display for on-site feedback and cloud-based data processing improved both usability and reliability. Testing confirmed accurate operation under varying conditions.

Overall, both systems provide practical, efficient, and scalable approaches to energy management. They demonstrate how intelligent control and real-time monitoring can enhance efficiency, safety, and sustainability in academic and industrial environments.

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