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Real-Time Application of Deep Learning to Human Detection System for Smart Room Power Management

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***Abstract*—** Population growth in residential, commercial and industry buildings have resulted in increasing demand for electrical power supply and energy. However, the limited available energy and power supply are characterized by wastage especially by the consumers. In addressing this problem, there is need to leverage on artificial intelligence (AI) for managing several energy or power sources and loads thereby saving more energy and cost. Thus, this paper presents a developed AI-based system named Intelligent Human-Sensing Power Management System (IHSPMS) that senses the presence of a human being to provide better monitoring and control of electrical appliances to save energy and cost. The IHSPMS provides smart room power management using digital web cameral as the sensing device and a microcontroller containing trained machine-learning (ML) model to detect humans in a room and appropriately triggers the relay to turn "ON" or "OFF" the room appliances. The system was tested with different scenarios and the results showed successful detection of human presence and absence in the room with switching "ON" and "OFF" of the appliances in each case as required. The proposed IHSPMS outperformed the non-AI based power management system in terms of energy efficiency.

***Keywords*—** Artificial Intelligence (AI), Deep Learning (DL), energy efficiency, power management, Smart home.

I. INTRODUCTION

Electrical energy is the most versatile energy required for many applications; and its usage is found in almost all areas of human endeavor to power appliances and equipment in residential, commercial and industrial buildings. As technology continues to advance and permeate our daily lives, the efficient use of electrical power is becoming increasingly crucial. High cost of fuel and increased cost per kilowatt hour of electrical energy consumed lead to increasing cost of production despite the rising daily demand for electrical energy [1][2]. Consequently, there is growing need for suggestions to help in the efficient usage of electrical energy, which would be of great profit to the consumers and providers. The traditional method for power management which is the manual switching on/off often fall short in addressing the specific issue of energy wastage when occupants leave a room [3][4]. In response to this, the growing need for innovative solutions that leverage on sensor technologies to automatically identify and power ON and OFF devices in a room cannot be overemphasized. The innovative control of appliances can be by gesture sensing, e.g. movement of the user's arm, occupancy detection or using Internet-of-Things (IoT) [5][6].

Studies have shown that the implementation of occupancy sensors in commercial buildings typically results in energy savings estimates range from 25% to 50% [7]. Smart home provides a means of coordination of home appliances or equipment via remote monitoring and control, which helps to achieve better electrical energy usage and management through informed decision thereby saving more energy and cost. Sensors and actuators are deployed in a building to collate data to make an informed decision for controlling and monitoring of home appliances by a microcontroller. The advantages of a smart home system include provision of more comfort and convenience, enhancement of security and safety of the occupants, improving interaction of home life and optimized resident's lifestyle [8-11].

By using Internet-of-Things (IoT) technology, remote home energy/power management system can been achieved to optimize energy consumption via controlling, scheduling and user information. Energy management system can monitor and adapt energy consumption behavior based on feedback received from smart homes. This is advantageous to the energy providers by reducing peak load demand and invariably the energy consumption cost [12-14]. The primary aim of this work is to mitigate energy wastage such as in unoccupied room and enhance overall energy efficiency, achieved through the utilization of occupancy sensors and AI technologies.

II. RELATED WORK

Smart power management systems consisting of sensing devices to detect parameters like temperature and occupancy has been proposed in [15]. It enables the connection of sensors and metering devices, utilizing both wireless and wired communication technologies. The drawback of this system is that it requires Internet connection. Sound sensors were employed in [16] to detect differences in noise levels between vacant rooms and those containing occupants. However, significant inaccuracies may occur when attempting to differentiate between various sound levels. The use of Passive Infrared (PIR) sensor was investigated in [17] to detect any movement of an object with a temperature above absolute zero. However, the PIR sensor exhibits reduced accuracy in detecting occupants with minor movements, such as those at arm or hand level, hence, false shutdowns can be triggered [18].

The use of cameras to observe the surroundings for adaptive power supply control to meet occupants' requirements has been proposed [19]. However, face detection approach faces the challenge of inaccurately detecting faces due to variations in lighting conditions, occlusion by objects or people, and changes in scale and orientation [20].

Most of the proposed innovative approaches of achieving power management for smart homes require connection to the Internet which may not be available regularly to the generality of consumers. In addition, the approaches that do not require Internet connection have been identified to some limitations such as inaccurate gesture detection and facial detection. Therefore, this paper is proposing the approach that employs deep neural network to detect an entire human body in the room rather than only the face, and without the need for Internet connection. Deep learning in artificial neural network has successfully found applications in different aspects of intelligent systems [21-23].

III. METHODOLOGY

3.1 System Block Diagram

The proposed Intelligent Human-Sensing Power Management System (IHSPMS) is shown in Fig. 1. The IHSPMS is built around the Raspberry Pi 4 Model B microcontroller. The microcontroller was programmed to detect human presence in the images captured by the two Logitech C270 720p HD webcams [24]. The two cameras are placed at angles that make the entire room to be visible to the cameras. The Raspberry Pi processes the video fed into it by the webcams to detect human presence in the captured images. The image feeds are passed to the trained Deep Neural Network (DNN) model to classify the images as containing a human being or not.

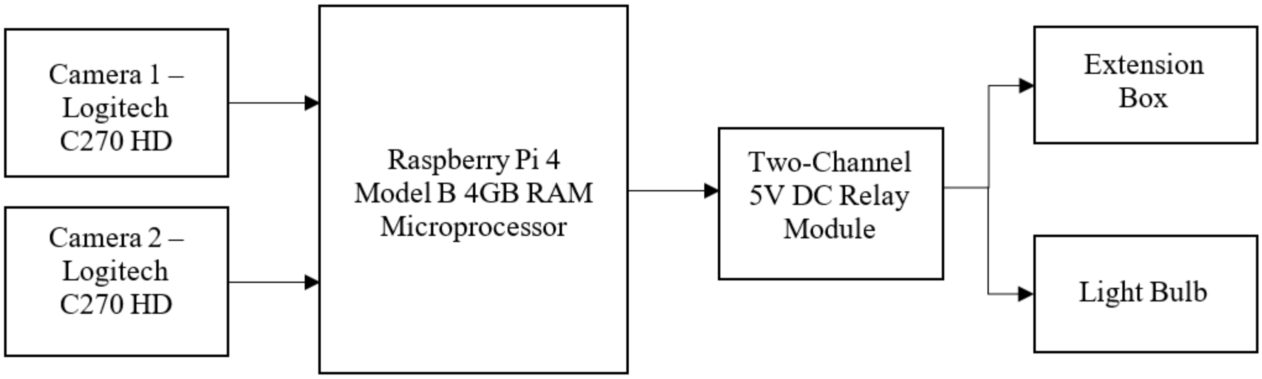

Fig. 1: *Block Diagram of the Proposed IHSPMS*

The system's operation starts with sensing by the cameras as shown in Fig. 2. If the system detects no human presence in the room, it will automatically turn off the connected appliances to conserve energy.

The DNN ensures accurate monitoring of the room's occupancy status. The output of the microcontroller energizes/de-energizes the relay module that controls the socket or extension box and light bulb. The system can be used to control any other appliance or equipment such as fans and television. The system's operation starts with sensing by the cameras as shown in Fig. 2. If the system detects no human presence in the room, it will automatically turn off the connected appliances to conserve energy.

3.2 Interfacing with the Webcams

Web cameras, also known as webcams, are digital cameras typically integrated into or attached to computer systems. Webcams capture video and sometimes audio in real-time, allowing users to communicate and interact over the internet [25]. The Logitech webcams used in this work, shown in Fig. 3, provide high-definition video feeds, capturing the visual data needed for human detection. These webcams are widely used for their reliability and compatibility with a range of computing platforms.

3.3 Interfacing with the Microcontroller

Various factors were considered while selecting the choice of microcontroller for this research, these include; application, processing power, peripherals, power consumption, development tools and support and the cost, considering these factors, the Raspberry Pi 4 Model B was carefully selected.

The Raspberry Pi 4 Model B, shown in Fig. 4, is a powerful single-board computer known for its versatility and affordability, it is made up of a quad-core ARM Cortex-A72 processor running at 1.5 GHz, offering improved performance for multitasking and multimedia applications with memory configurations ranging from 2GB to 8GB of LPDDR4 RAM, with users being able to select level of performance which suit their purpose.

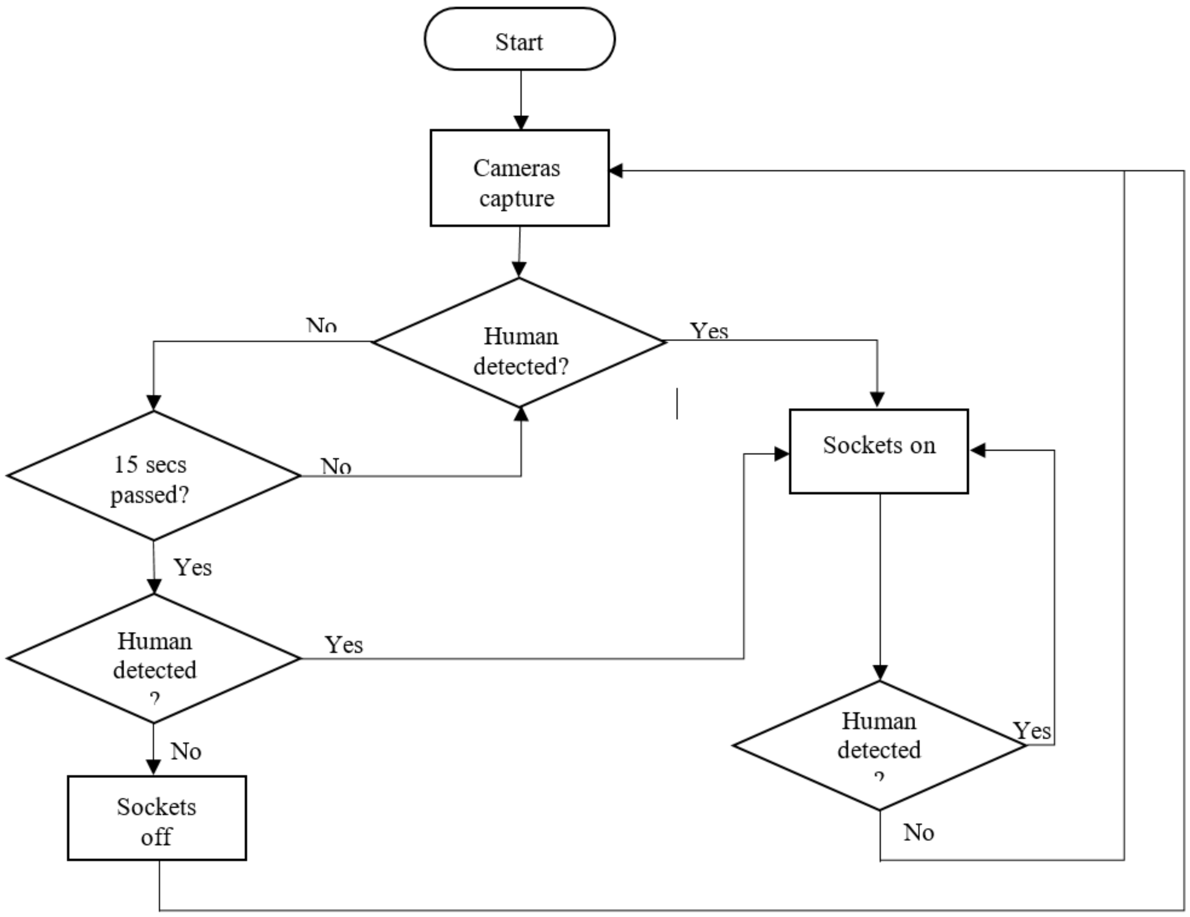

Fig. 2: *System Flowchart*

Fig. 3: *Logitech C270 HD Webcam*

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Fig. 4: *Raspberry Pi 4 Model B*

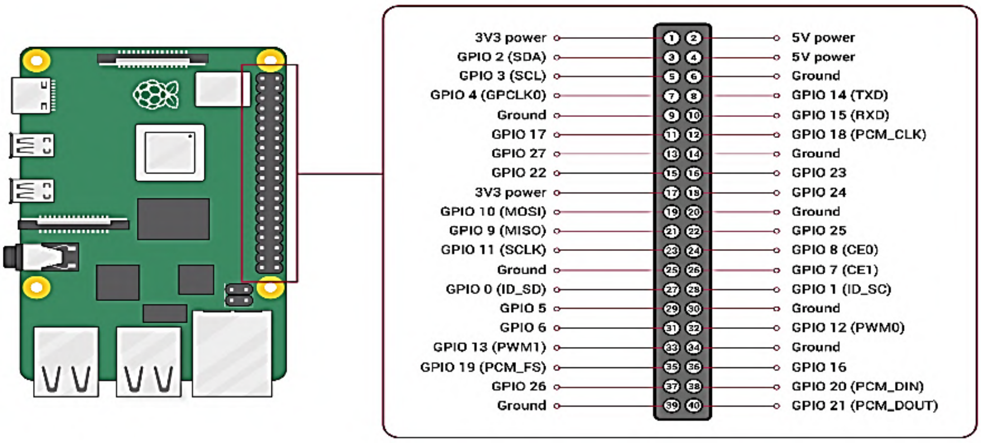
The Raspberry Pi 4 contains 40-pin GPIO header, as shown in Fig. 5, for interfacing with sensors and peripherals, Gigabit Ethernet for wired networking, and USB 3.0 and USB 2.0 ports for connecting peripherals. The Raspberry Pi 4 Model B runs on Raspberry Pi OS, an open-source Linux-based operating system [26]. To facilitate efficient interaction and programming of the Raspberry Pi, a two-step remote connection was established.

Initially, Secure Shell (SSH) was used to establish a secure command-line interface, enabling remote access to the Raspberry Pi's terminal. Subsequently, a connection through Virtual Network Computing (VNC) viewer was established, as shown in Fig. 6, providing a graphical desktop environment for seamless visualization and control of the raspberry Pi's interface which allows for effective remote management and programming of the microcontroller. An integrated development environment (IDE) called “Thonny”, as shown in Fig. 7, was utilized to program the Raspberry Pi in Python programming language. An overview of the entire system interface is presented in Fig. 8.

3.4 Power and Energy Consumption

Electrical power consumption is directly proportional to energy consumption described by Equation (1) as:

$$P = \frac{E}{t} \quad \text{………………………… (1)}$$



*. **Fig. 5:** Raspberry Pi 4 Model B GPIO Pins*

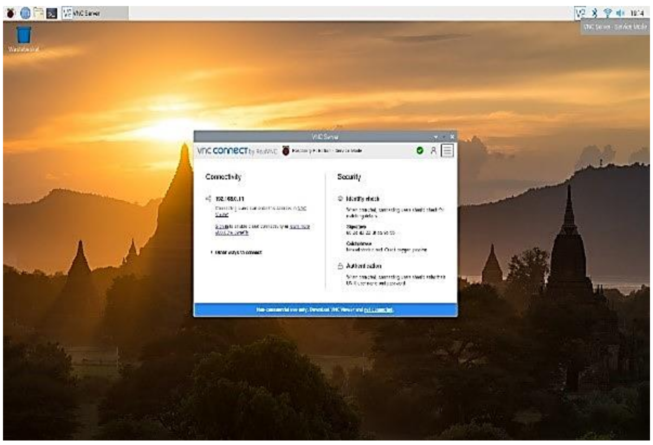


Fig. 6: *Virtual Network Computing (VNC) Viewer Window.*

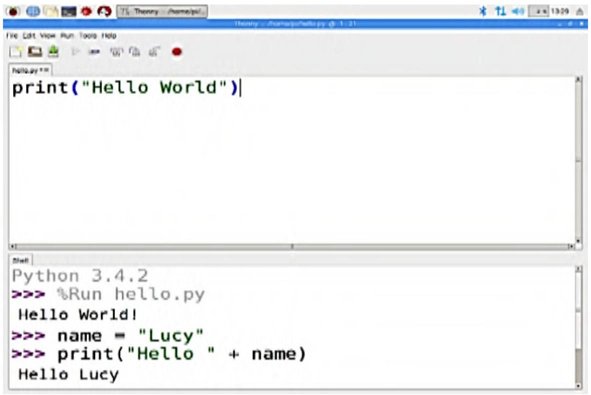


Fig. 7: *Thonny Window on Raspberry Pi*

Where P is the power consumed (in watts, W), E is the energy consumed (in joules, J), t is the time for which the power is consumed (in seconds).

The power-energy relationship reveals that reduction in power consumption by loads would invariably reduce the amount of energy dissipation; and this would translate to fuel economy for generators utilizing fossil fuel.

3.5 Deep Neural Network (DNN) Model

The task of the Deep Neural Network (DNN) model in the proposed IHSPMS system can be summarized in the following steps:

Step 1: Detect the presence of a target object in a scene

Step 2: Localize the object

Step 3: Classify the object

The DNN model was trained for human detection using the Common Objects in Context (COCO) dataset and the Single Shot Multi-box Detector (SSD) object detection model. The COCO is a large-scale dataset designed for object detection, segmentation, and captioning tasks in computer vision [24].

The trained DNN model was loaded for object detection through OpenCV and python programming language in the Raspberry Pi 4 Model B [27][28].

The OpenCV is a library suitable for loading a pre-trained human detection model from the COCO dataset and performs inference on the input images. It displays the output image with bounding boxes drawn around detected humans.

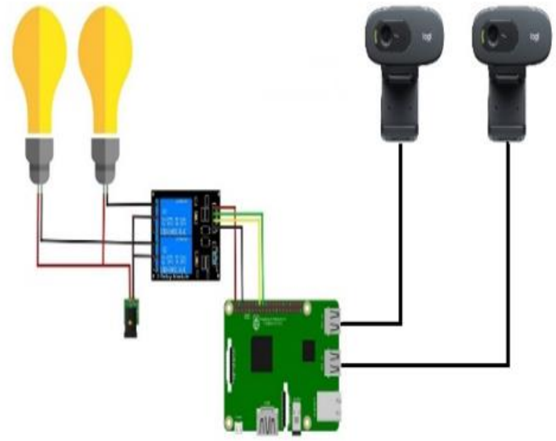


Fig. 8: *System Interface*

The bounding box is achieved by the SSD model. The SSD model is based on Convolutional Neural Network (CNN) architecture, and the process for training the SSD is shown in Fig. 9.

The training process involves assigning the actual box (i.e. the actual object location) in an image to each of a set of default (i.e. the predicted) boxes; and if the overlap value between the actual box and a default box is higher than 0.5, the given threshold, then there is a match which the SSD model learns.

Localization and confidence losses are calculated during the training to improve the model's prediction rate, and the training data were augmented with transformed images by cropping, flipping and rotating for better generalization by the SSD model for object detection in real-time [15].

The SSD Mobile-Net V3 aligns with COCO for human detection. The continuously recorded frames from the webcams is passed to the DNN model to identify people within each frame, in line with the COCO dataset.

Convolutional Neural Network (CNN) is a class of DNN commonly used for computer vision, pattern recognition and object classification. The major aspect in CNN training for image classification is the convolution operation which can be expressed as:

$$(I \otimes F)(i,j) = \sum_{m}\sum_{n} I(i+m, j+n)F(m,n)$$

……………………….(2)

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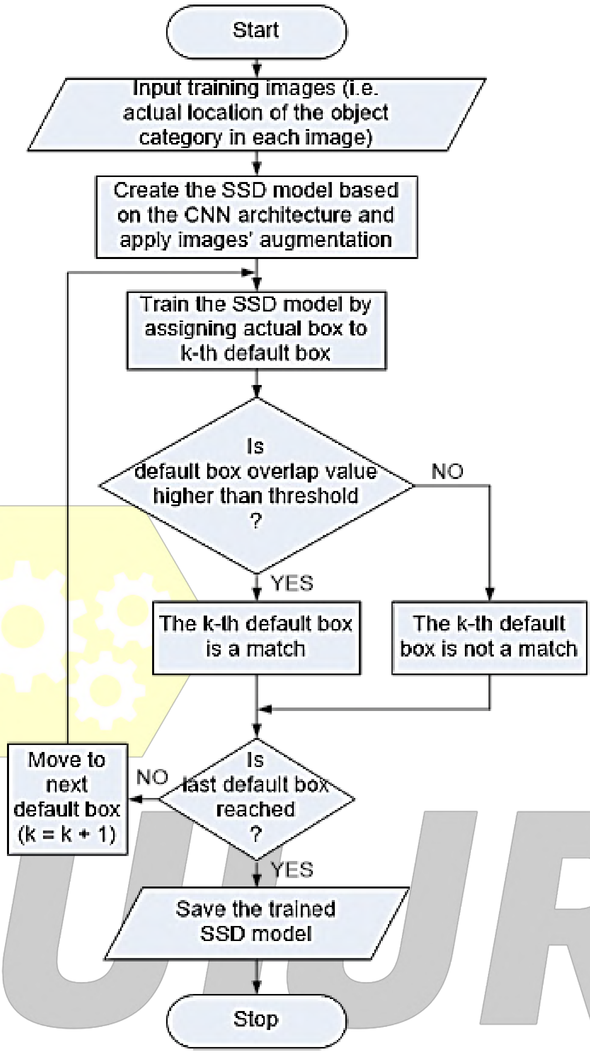

Fig. 9: *Flowchart of the training of Single Shot Multi-box Detector (SSD) model*

where I is the input image or feature map; F is the filter (convolutional kernel), (i, j) is the position of pixel in the output feature map m and n are the indices of the filter

IV. RESULTS AND DISCUSSIONS

The developed Intelligent Human-Sensing Power Management System (IHSPMS) was tested in a room for real-time detection of a human being and the system worked correctly. Once a person is detected in the video stream, a rectangular bounding box was drawn around the detected person as shown in Fig. 10. When a person is detected, a signal is passed on the output mode GPIO pins, triggering the relay connected to it which turns ON all the devices connected to it, as shown in Fig. 11, indicating the detection of a person in the surveillance area. On the other hand, if no human is no,

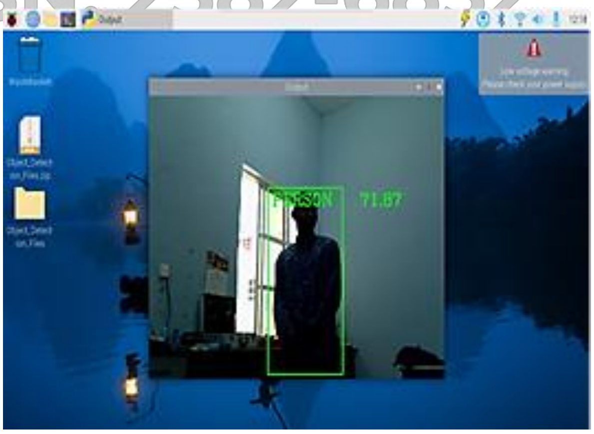

Fig. 10: *Bounding Box Around Detected Person*

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Fig. 11: *Appliances (light bulb) Turned ON*

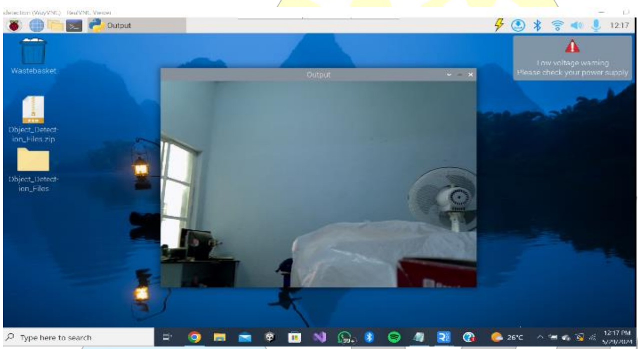

Fig. 12: *No Human Detected - No Bounding Box*

Fig. 13: *Appliances Turned OFF*

Human is detected after a certain interval 15 seconds in this case, the relay turns OFF all the devices connected to it as shown in Fig. 12 and Fig. 13. During system operation, a print statement is provided on the console. Whenever a person was detected, a message stating "Relay is ON" was printed to the console. When no person was detected the console output displayed "Relay is OFF". This continuous feedback loop facilitated effective monitoring and debugging.

Table 1: *Summary of Result*

	ACTUAL ROOM STATUS	SYSTEM RESPONSE		
Scenario	Room status	Person detected	Delay	Relay state
A	No human is present	NO	15 seconds	OFF
B	Human is present	YES	None	ON

The performance of the proposed IHSPMS is compared with two other methods namely Passive Infrared Detector (PID) method and Facial Detection (FD) method for the two scenarios – A (No human is present) and B (Human is present). The methods are compared using Average detection rate as the performance metrics. Fig. 14 presents the results for scenario A in which no human is present in the room.

The IHSPMS, PID and FD methods gave average detection rate of 100%, 82% and 88% respectively. Whereas, for scenario B in which human being is present in the room, shown in Fig. 15, the IHSPMS, PID and FD methods gave average detection rate of 100%, 85% and 90% respectively. These reveal that the proposed IHSPMS method outperforms both the PID and FD methods. The reason is because the deep learning in the IHSPMS method helps to overcome the variation in lighting, occlusion, and change of orientation of objects associated with the FD method.

VII. CONCLUSION

The limited available energy and power supply are characterized by wastage especially by the consumers. In consequence, there is need for innovative solutions that leverage on sensor technologies to automatically identify and power ON and OFF appliances and equipment in a room. In this paper, an Intelligent Human-Sensing Power Management System (IHSPMS) has been developed. The IHSPMS system utilizes Deep Neural Network (DNN) to detect the presence or absence of a human being in a given room to provide better monitoring and control of electrical appliances at high accuracy. The results obtained showed that the proposed IHSPMS is a robust strategy to save energy, reduce cost and enhance overall energy efficiency for both the providers and consumers. In addition, the

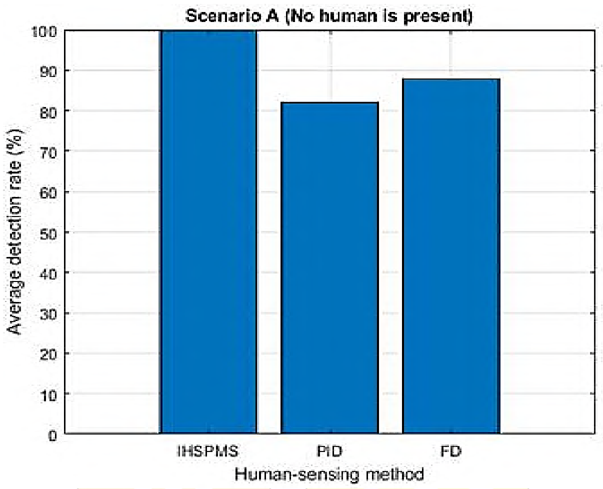

Fig. 14: *Average Detection Rate Performance for Scenario A (No Human is Present)*

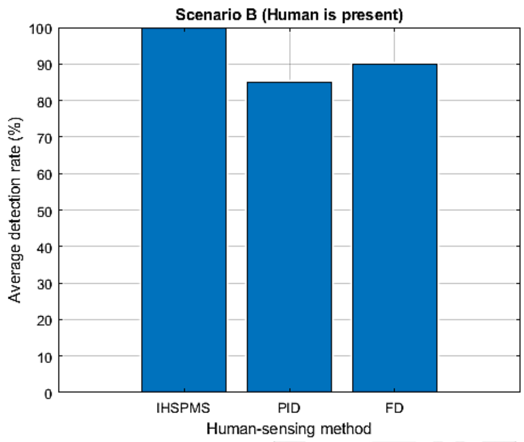

Fig. 15: *Average Detection Rate Performance for Scenario A (Human is Present)*

Motivation behind this proposed system is to provide an alternative to the IoT-based approach since the proposed system can be utilized without the requirement for Internet connection that is associated with IoT systems.

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