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Research Paper

Automatic Ceiling Fan Control Using Temperature and Room Occupancy

Benjamin Kommey [1], John Kwame Dunyo[1], Bright Yeboah Akowuah[1], Elvis Tamakloe[2]

[1] *Department of Computer Engineering, Kwame Nkrumah University of Science and Technology, PMB Knust, Kumasi, 00233, Ghana*
[2] *Department of Electrical Engineering, Kwame Nkrumah University of Science and Technology, PMB Knust, Kumasi, 00233, Ghana*

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CORRESPONDENCE

Phone: +233 50 7703286
E-mail: bkommey.coe@knust.edu.gh

A B S T R A C T

This paper presents the design and implementation of an automatic ceiling fan speed regulator using web camera and a temperature sensor. Fans have become a very important aspect of our daily lives to present us with comfort especially in hot climates. However, they come with some attendant issues such as a person having to move to where the fan regulators are placed to be able to adjust the speed of the fan. This can be difficult as temperatures change during the day as well as at night when one is asleep. This also poses a problem for physically challenged individuals with mobility difficulties. This project seeks to design a solution that involves automatic fan regulation. This was achieved using a temperature sensor, a camera that captures images, and a system intelligent unit that processes the captured images to detect occupancy. The speed of the fan is then automatically adjusted based on the room temperature and occupancy. The system was implemented on a raspberry pi, a resource constrained edge computing environment.

INTRODUCTION

The electric fan is one of the most common electrical devices found in almost every home. They are particularly used in homes to control room temperature. Since the invention of the first electric fan in 1882 by Philip Diehl, they have gone through many changes and improvements [1]. Over the years, they have become an integral part of our home environment to give us comfort by cooling our bodies in hot and humid climates. The ceiling fan has a motor that converts electrical energy into mechanical energy. As hot air rises, the blades of the fan slice this air and push it down. This continuous process causes air to circulate in the entire room. The continuous circulation mixes hot and cold air in the room and in effect reduces the temperature to an average value [1]. Demand for the accurate temperature control has conquered many of industrial domains. Automatic temperature control is important to maintain a comfortable environment [2]. Fans come in different forms such as ceiling fan, table fan, wall-mounted and pedestal fans with special applications [3].

Although fans have become such a vital part of our lives, they have their attendant issues. Almost all available ceiling fans today are manually regulated using voltage regulators or control knob [8]. In a room where there is more than one fan; as is often the case for large places like classrooms, offices, living room among others, each fan comes with its own regulators which is placed on the walls of the room. This creates an appearance that is not very attractive. Besides, the room temperature changes at the different times in the day and thus the need to achieve a desired room temperature. With the existing method, one needs to move to the regulator and manually adjust the fan speed. This is particularly disadvantageous to the physically challenged and other people with mobility challenges. There is also a growing concern for automation of ceiling fans as it not only saves electricity by going off when they are not required, but also ensure comfortability by offering remote and intelligent control [10].

This project therefore seeks to design and implement a smart regulator that automatically adjust the fan speed based on room temperature and occupancy. Thus, in this paper, we explore the use of a low-resolution web camera and a temperature sensor to automatically control the speed of the ceiling fan. In our approach, we developed an optimized occupancy detection algorithm that inspects the feeds from the low-resolution webcam to detect and locate room occupancy. The occupancy detection model uses Histogram of Gradient (HOG) to extract the human features from the feeds which are then classified using SVM to improve the accuracy of the detection. The model also locates room occupancy, thereby allowing only fans within the occupancy region to be switched ON/OFF based on room temperature. The proposed system is applicable in both single room and large room settings.

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RELATED WORKS

A critical analysis of previous studies on the subject matter and related fields was carried out to assist the design and implementation process.

In [4], a simple infra-red (IR) remote controlled fan regulator with a display unit was developed as an alternative to the traditional wall mounted regulator. Cost reduction using locally available materials was huge factor considered during implementation. Although the remote control serves to eliminate the inconvenience of moving to the wall mounted regulator to turn on/off the fan, there is also the possibility of the remote control getting misplaced or damaged easily because it must be moved from one place to another. An attempt to keep it at one place will bring back the initial problem of having to move to where it is kept, to regulate the fan. [4] used an IR sensor, monostable vibrator, decade counter, transformer, zero crossing detector, opto-isolator, and TRIAC to implement the receiver circuit of a remote-controlled fan regulator that works with any modern-day remote control i.e., any remote control used for TV, VCR, Air-Conditioner, DVD player etc can be used to regulate the fan. In this study attention was paid only to the receiver unit.

[5] and [6] in their works implemented microcontroller based automatic fan speed regulator using a temperature sensor. The sensor typically reads the temperature of the room and changes the speed of the fan based on some predefined temperature ranges that correlate to specific speeds. [7] designed an RF remote temperature speed-controlled fan that operated in two modes: manual and automatic. The system has a transmitter and receiver unit, the transmitter unit is made up of the RF remote and the receiver unit which is attached to the fan body receives the RF signal and consists of a temperature sensor. In automatic mode, the system control unit (PIC16F877A Microcontroller) in the receiver carries out speed control based on signals received from the temperature sensor. In manual mode, the system is controlled by the (RF) remote control that transmits signals to the receiver unit. The speed of the fan is determined based on the button pushed. The remote can also be used to switch between modes (manual and automatic). Also included in the system is an LCD display that shows the current mode of operation, temperature in the room and fan speed.

[8] proposed a GSM fan speed regulator using mobile phone. They used the existing Dual Tone Multi-Frequency (DTMF) generated from the keypad of the mobile phones of the user to remotely regulate the speed of the fan. Their proposed system has three (3) different speed levels and the ability to turn the fan off and on. This is particularly beneficial to the aged and the physically challenged persons with mobility constraints as it will enable them to adjust the speed of the fan at the comfort of their beds or wheelchairs without the need to move. However, the inconveniences of always waking up to adjust the fan's speed due to the changing room temperature have still not been taken care of. [9] designed a low-cost smart electric fan that uses triac instead of relays. In their design, a LM35 temperature sensor is used to measure the temperature of the room and then fed directly to the ADC of the PIC microcontroller. The PIC microcontroller has an inbuilt PWM module that controls the speed of the fan by varying the duty cycle. According to their experimental results, the use of the triac significantly reduces power consumption. Similar design was also proposed by [10]. However, their proposed systems lack the ability to detect room occupancy, thus would automatically turn on even if there is no one in the room.

Although quite a lot of research have been done to achieve automatic fan speed regulations, there are still many problems needing attention. For example, the need to take into consideration room occupancy and comfort of the occupants for automatic regulation. This not only improves occupants' experience but also helps in energy conservation. Therefore, to solve these existing challenges and keep up with the growing trend of home automation, there is the need to develop more robust systems that take into consideration room occupancy and occupants' comfort to ceiling fan regulations.

MATERIALS AND METHODS

System Architecture

The heart of the system is the System Intelligent Unit (SIU), As shown in Figure 1. The SIU receives inputs from the temperature sensor and the camera and used the received input data to automatically regulate the speed of the fan via a special speed control circuitry. This process is summarized in the system block diagram shown in Figure 2.

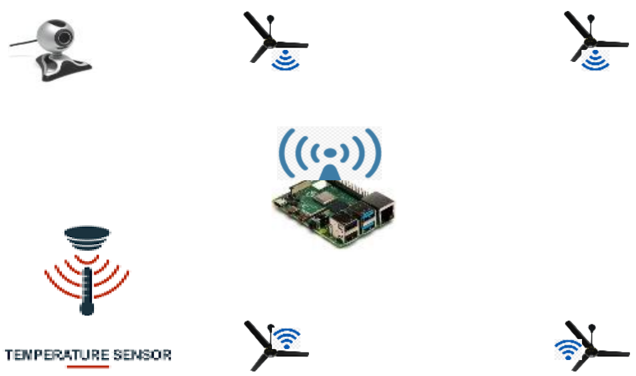

Figure 1. System Architecture

System Block Diagram

The system consists of several parts, i.e. sensor unit, fan speed control, system intelligent unit, AUX Port and CF Port, as shown in Fig.2

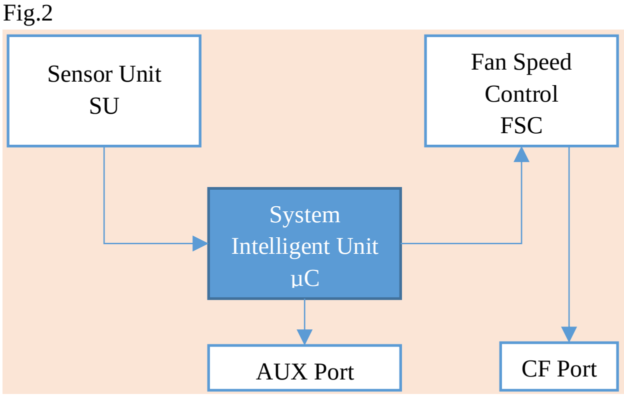

Figure 2. System Block Diagram

Each of these parts is described below:

a) Sensing Unit

The sensing unit comprises of two main sensors: a 3D USB camera and a Si7021 temperature and Humidity sensor.

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b) Temperature Sensor
In sensing the ambient temperature, a low cost Si7021 temperature sensor was used. The Si7021 sensor is a monolithic CMOS IC (Complementary Metal-Oxide-Semiconductor Integrated Circuit) integrating humidity and temperature sensor elements, an analog-to-digital converter, signal processing, calibration data, and an I2C Interface [12]. This allows easier interfacing with a wide range of microcontrollers. It has a temperature Accuracy of ±0.4℃ within -10 ℃ to 85℃, making it ideal for room temperature measurements.

c) Camera
The camera used is a conventional 3D USB web camera with a maximum resolution of 1080 pixels. It has a field angle of 90 degrees that allows it to capture more objects within its view [13]. This is particularly ideal for occupancy detection in larger rooms or halls as measurement taken at distances less than 2m produce broader scenes. It sends captured images to the SIU for further analysis through a USB port on the SIU. The SIU also supplies power to the camera via the same port.

d) System Intelligent Unit
The system intelligent unit is the main controlling circuitry of the project. The processor used is a Raspberry Pi 3 Model B+. The Pi 3 Model B+ is a powerful single-board computer developed by the raspberry foundation. It has a 64-bit ARM Cortex-A53 quad-core processor at a clock speed of 1.4GHz. This Model has a 1GB LPDDR2 SDRAM with an extended 40-pin GPIO header allowing for many connections. It operates with a 5V direct voltage [14].

e) Speed Control Unit
The speed control unit is designed to regulate the speed of the fan based on the signals from the system intelligent unit. This is achieved through PWM by varying the duty cycle of the input pulse signal from the SIU [16]. A buffer circuit is built with an NPN transistor and Schottky diode to protect the SIU pins.

Proposed System Implementation

The implementation architecture for the proposed system is shown in Figure 1. The SIU constantly monitors the signals from the camera to detect room occupancy. Once room occupancy is detected, the SIU then reads the temperature from the Si7021 temperature sensor and then adjust the speed of the fan accordingly via the speed control circuitry.

Room Occupancy Detection

Room occupancy detection involves detecting the presence of humans in a room. There are several open-source deep learning algorithms used in object detection such as Haar features and gradient orientation features. Other different classifiers such as Nearest Neighbor, Neutral Network SVM and Adaboost can also be used [17,18].

The image from the USB camera is first processed to increase its size and quality. This is termed rescaling. Rescaling significantly increases the image quality while reducing the aliasing effects. The rescaled image is then passed through a blob algorithm that detects blob shapes in the image. People appear to have a round 'blob' shape, thus the blob algorithm. Finally, the detection results are extracted and superimposed on the rescaled image.

The room occupancy model developed in this project uses the Histogram of Gradient (HOG) algorithm. The HOG was proposed by Dalal and Triggs in 2005 and is the most popular algorithm for human detection [25, 26]. This approach utilises the dense grids of the HOG to extract human features from the camera feeds and classify them using the SVM algorithm. In developing the occupancy detection model, three (3) steps were followed: (i) extraction, (ii) training and (iii) detection. The proposed occupancy detection model is shown in Figure 3.

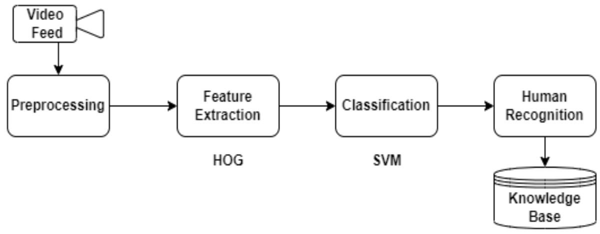


Figure 3. Occupancy detection model

It has several individual processes. First, the video feed is pre-processed. In the pre-processing stage, the video feed is converted into frames. Each frame, cropped to 64 x 128 pixels undergoes semantic segmentation. The main purpose of semantic segmentation is to mark all human objects in the frame into one class, thereby allowing human objects to be separated from the background or other objects. The HOG algorithm is applied on the dataset to extract possible human features. The next stage is classification using the SVM (support vector machine). The classification results are used to recognised humans by comparing the extracted features with the features in the knowledge base. The results are stored back in the knowledge base for future references. The model was implemented with OpenCV, a popular open-source computer vision library.

Control Mechanisms

The system has 4 speed control levels: Off, Low, Medium, and High. Each of this level is selected base on the occupancy detection and room temperature. The fan is set to OFF when occupancy is not detected but room temperature goes up. Table 1 shows the conditions necessary for each level to be selected.

Table 1: Speed control table

Camera (Occupancy Detection)	Temp Sensor (Room Temp ºC)	Fan Speed
yes	T < 20ºC	OFF
yes	20-24 ºC	LOW
yes	24-28 ºC	Medium
yes	>=28 ºC	High
no	T < 20 ºC	OFF
no	20-24 ºC	OFF
no	24-28 ºC	OFF
no	>=28 ºC	OFF

System Workflow

The logical representation of the software code has been presented in the flowchart shown in Figure 4.

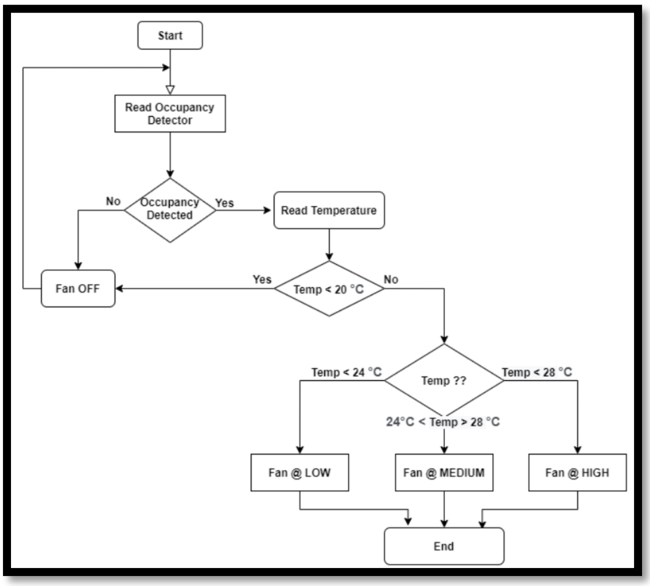


Figure 4. System Flow Chart

Firstly, the occupancy detector is run to check the feeds from the camera for room occupancy. If no occupancy is detected, the Fan is turned OFF. If occupancy is detected, the SIU reads the room temperature from the Si7021 temperature sensor. The fan remains OFF if the temperature is below 20 ºC. However, the fan is turned ON if the temperature is more than 20 ºC. The speed control circuitry has three (3) speed levels which are triggered based on the temperature.

The fan's speed is set to LOW if the room temperature is between 20 and 24 ºC. It is set to Medium when the temperature falls within 24 ºC to 28 ºC. The fan speed is set HIGH for temperatures higher than 28 ºC

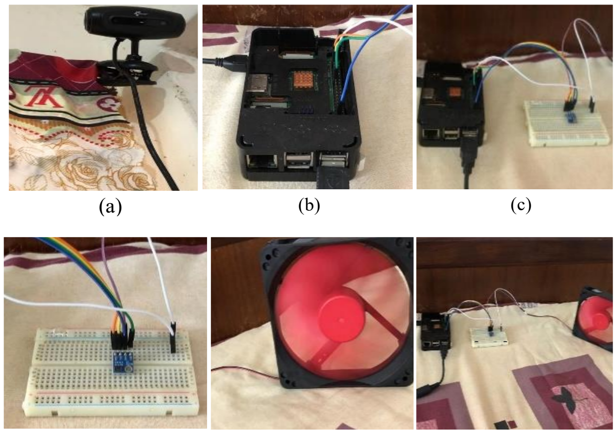
RESULTS AND DISCUSSION

For testing purposes, the system was implemented on breadboard and piloted in a various environmental setting as follows:

- Bedroom
- Big hall
- Lecture theater
- Auditorium

The sensing unit comprising the 3D web camera is mounted at the ceiling. This position ensures little or no obstructions in the field of view of the camera as shown in Figure 5a-f. The system intelligent unit (SIU) and the speed control unit are embedded together in a single unit (Figure 5b) and placed at a cool position in the room. This is very necessary to ensure the processor's temperature remains under ideal conditions. A 12V brushless DC fan is connected to the output of the speed control circuit and placed closer to the SIU as shown in Figure 5f.

To visualize and measure the effectiveness of the system, a laptop computer is connected to the SIU via SSH protocol. On the laptop, the room temperature and the fan speed are observed, together with the throughput of the system, and accuracy of the occupancy detection model.



(a) (b) (c) (d) (e) (f)

Figure 5. Various test positions: (a) mounted webcam; (b)embedded processing unit; (c) embedded processing unit and speed control unit; (d)speed control unit; (e) spinning fan; (f) complete setup

It was observed that the system responded satisfactorily to the temperature changes in the room and room occupancy. Tests were repeated and the system provides same results for same condition multiple times as was expected. It was also observed that the proposed system conserves energy and can detect room vacancy and then turned off the fan. The main observed disadvantage of the proposed system is the constant heating of the SIU. This was however mitigated by bringing it closer to the fan, such that the fan cools it down.

To further test the system two additional experimental test scenarios were set up to investigate the performance of the proposed system. The first scenario was a single bedroom with only one ceiling fan. The second is a hall with multiple fans.

Hall and Larger-room Set-up

This setting is applicable to larger rooms or halls with more than 1 fan. To fully cover the length of the hall or larger rooms, the cameras are arranged according to their individual ground width to cover the whole room. The ground coverage width of the camera is computed using equation 1. This is summarized in figure 6.

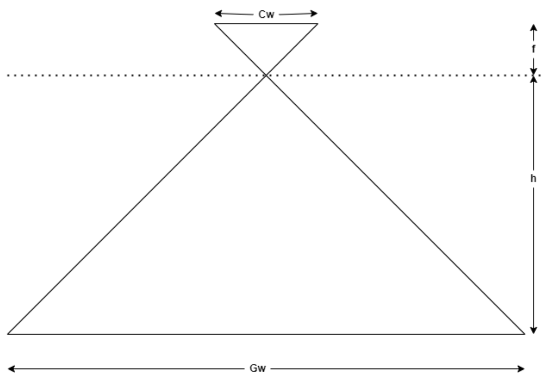


Figure 6. System camera positions to calculate ground width

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$$G_w = C_W \, x \, hf \quad (1)$$

The fan's locations within the camera's ground coverage width is measured and recorded in terms of pixel coordinate; given by equation (2)

$$F = (F_x, F_y) \quad (2)$$

The centroid of the rectangle produced from the occupancy detection algorithm is assumed as the actual location of the individual in the room. It is measured in terms of the pixel coordinate, given by equation (3)

$$C = (C_x, C_y) \quad (3)$$

The magnitude of the displacement of the individual's location **C** from each of the fan **F** is computed using equation (4).

$$CF_i = (C_{x-}F_{ix})2 + (C_y - F_{iy})2 \quad (4)$$

where i is the fan number.

The fan that produces the smallest result (ie ||CF||) is taken to be closet to the individual detected, and thus turned on. Its speed is regulated based on the temperature of the room.

To visualize and measure the effectiveness of the system, a laptop computer is connected to the SIU via SSH protocol. On the laptop, the room temperature and the fan speed are observed, together with the throughput of the system, and the accuracy of the occupancy detection model. The operating temperature of the SIU is also closely monitored. Figure 7 shows a screen shot of some parameters observed during run time.

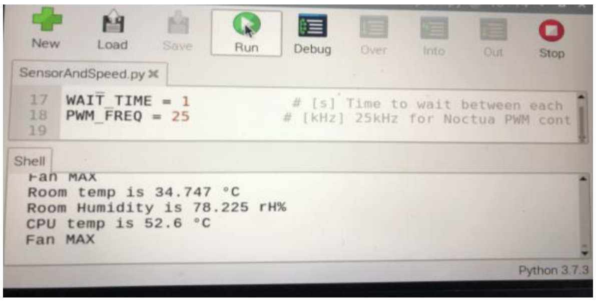

Figure 7. Some system parameters observed during run time

In the first experimental scenario, the system responded satisfactorily to the temperature changes and room occupancy. The occupancy detection model was able to detect various human postures in the room at a varied frame rates in figure 8. According to the experimental result, the system took a lot of time to detect and room occupancy and respond to it at higher frame rates. Thus, the frame rate was adjusted to 3 fps to ensure the model runs smoothly. The results are tabulated in table 1.

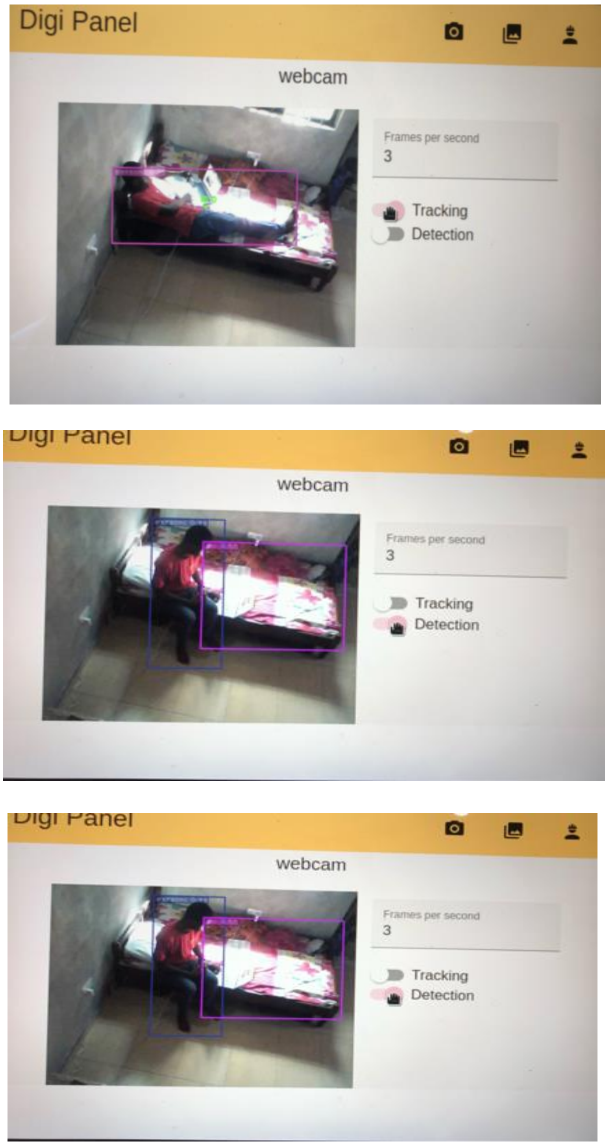

Figure 8. Human postures in a room with accuracy predictions

In the second experimental scenario, the system also responded satisfactorily to the temperature changes and room occupancy with appreciable increase in CPU temperature. The accuracy of the localization algorithm was also measured. The results are tabulated in table 2 and 3.

Table 2 Results for experimental scenario 1

Test Scenario (A)	Occupancy	Room Temp (°C)	Occupancy Detection Accuracy (%)	Response time (s)	Frame per second(fps)	Fan Speed
1	yes	34.9	79.2	6.55	5	HIGH
	no	29.8	85.3	5.39	5	LOW
2	yes	31.5	65.8	6.18	4	HIGH
	no	32.7	78.0	5.05	4	OFF
3	yes	24.3	60.4	4.47	4	MEDIUM
	no	24.1	91.8	4.22	4	OFF
4	yes	30.3	77.1	4.35	3	HIGH
	no	34.8	92.0	3.39	3	OFF
5	yes	29.7	72.2	3.44	3	MEDIUM
	no	30.1	87.1	1.44	3	OFF
6	yes	20.9	76.3	3.01	3	LOW
	no	22.8	85.4	1.50	3	OFF

According to the experimental results, the system performs well at detecting no occupancy than occupancy. This was due to the HOG feature extraction used in developing the model. The overall response time of the second scenario is higher than the first scenario due to the combined effect of the response time of both the occupancy detection and the occupancy localization algorithms. It was also obviously observed that the proposed system conserves energy. It can detect room vacancy and then turned the fans off. The main observed disadvantage of the proposed system is the constant heating of the SIU. This has affected the response time of the system as the system takes longer time to respond when the CPU temperature is high. This was however mitigated by bringing it closer to the fan, such that the fan cools it down

.

Table 3: Results for experimental scenario 2

Test Scenario (A)	Occupancy	Room Temp (°C)	Occupancy Detection Accuracy (%)	Occupancy Localization Accuracy (%)	Response time (ms)	Frame per sec. (fps)	Fan Speed
1	yes	34.9	79.2	68.1%	10.10	5	HIGH
	no	29.8	85.3	-	5.05	5	LOW
2	yes	31.5	65.8	61.2%	8.49	4	HIGH
	no	32.7	78.0	-	6.27	4	OFF
3	yes	24.3	60.4	73.6%	8.53	4	MEDIUM
	no	24.1	91.8	-	8.06	4	OFF
4	yes	30.3	77.1	69.3%	7.30	3	HIGH
	no	34.8	92.0	-	6.20	3	OFF
5	yes	29.7	72.2	80.5%	7.28	3	MEDIUM
	no	30.1	87.1	-	7.00	3	OFF
6	yes	20.9	76.3	74.1%	6.01	3	low
	no	22.8	85.4	-	6.45	3	OFF

CONCLUSIONS

In this paper, an automatic ceiling fan speed regulator based on room occupancy and temperature was implemented. Videos coming from a webcam mounted in a room were analyzed by algorithms to detect the presence or otherwise of people. The room temperatures were used to automatically control the speed of the fan. The project was implemented on a resource constrained edge computing environment, i.e., Raspberry pi but performs better as expected. The system also performed satisfactorily well in conserving energy and thus can be used in smart home applications.

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