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Integrating Face Detection and Energy Monitoring for Enhanced Energy Suitability in Room Environments

***Abstract**. Addressing energy-related issues is imperative in our modern world. This study presents a unique solution for monitoring and optimizing electrical power consumption by integrating a face detection system with the NETPIE platform. The system incorporates motion sensors, a Raspberry Pi with a camera, and NETPIE to accurately detect and quantify the number of occupants in a room in real-time. By combining data from these sources, the system can determine the occupancy level and correlate it with electricity usage. Test results demonstrate the system's effectiveness in evaluating energy suitability, providing a percentage-based indicator of performance. This innovative approach offers a promising solution to energy problems by offering insights into energy consumption patterns based on occupancy. It enables more informed decision-making and improved energy management strategies. With its potential to enhance energy efficiency, this system represents a significant step towards a more sustainable and eco-friendly future.*

Streszczenie.** Zajęcie się kwestiami związanymi z energią jest koniecznością we współczesnym świecie. W niniejszym opracowaniu zaprezentowano unikalne rozwiązanie monitorowania i optymalizacji zużycia energii elektrycznej poprzez integrację systemu detekcji twarzy z platformą NETPIE. System składa się z czujników ruchu, Raspberry Pi z kamerą i NETPIE, które umożliwiają dokładne wykrywanie i określanie ilości osób w pomieszczeniu w czasie rzeczywistym. Łącząc dane z tych źródeł, system może określić poziom obłożenia i skorelować go ze zużyciem energii elektrycznej. Wyniki testów wykazują skuteczność systemu w ocenie przydatności energetycznej, zapewniając procentowy wskaźnik wydajności. To innowacyjne podejście oferuje obiecujące rozwiązanie problemów energetycznych, oferując wgląd we wzorce zużycia energii w oparciu o obłożenie. Umożliwia bardziej świadome podejmowanie decyzji i ulepszone strategie zarządzania energią. Dzięki potencjałowi poprawy efektywności energetycznej system ten stanowi znaczący krok w kierunku bardziej zrównoważonej i przyjaznej dla środowiska przyszłości.* (Integracja wykrywania twarzy i monitorowania energii w celu zwiększenia przydatności energetycznej w pomieszczeniach***)

Keywords: Energy Monitoring, Face Detection, Room Environments, Occupancy Detection, Electrical Power Consumption.
Słowa kluczowe: Monitorowanie energii, wykrywanie twarzy, otoczenie pomieszczenia, wykrywanie obecności, zużycie energii elektrycznej.

Introduction

In our rapidly evolving world, the pressing concerns of energy efficiency and sustainability have taken center stage [1]. The inexorable rise in the demand for electrical energy has necessitated the pursuit of innovative solutions that not only optimize consumption but also minimize the detrimental environmental impact [2]. The Internet of things (IoT)-based study embarks on a comprehensive exploration into the development and evaluation of a Smart Building system, which revolves around a Arduino or Raspberry Pi-based platform. Its primary objectives include the monitoring of electrical power consumption and the simultaneous detection and quantification of occupancy levels within indoor spaces. Such an integrated system represents a highly promising avenue for enhancing energy management strategies, as it leverages real-time occupancy data to inform decision-making and significantly contributes to the overarching objective of creating sustainable and eco-friendly environments [3], [4].

The development in [4], the image processing-related core motivation behind efficient energy research lies in the imperative need to bridge the gap between energy consumption and efficient utilization. However, the [4] idea is to connect interactive visualization with human-generated movements and the server-side cloud backed by IEEE1888 data storage and FETCH/WRITE. Interactive Display as a Service (IDaaS) integrates Processing programming for interaction graphics and Microsoft Kinect for gesture detection. In addition, the [2] applied energy suitability formula to compute the number of people and energy usage. Previous work in [4] and [5] are interested in combining the ideas by using people's automatic detection and energy suitability computing for room energy management systems.

To implement, the IoT employs a multi-sensor approach, incorporating devices such as the DHT22 sensor for humidity and temperature, a motion sensor, and a light sensor. These sensors, in conjunction with an ESP8266 microprocessor, enable the collection of valuable data on environmental conditions and occupancy. The system applied Network Platform for Internet of Everything (NETPIE) is a cloud platform designed by Thai researchers, specializing in IoT applications. It facilitates efficient device management and data communication [7]. Furthermore, the Raspberry Pi's capabilities as a versatile computing platform provide the necessary computational power for data analysis and system management [8].

A pivotal aspect of this study is the real-time correlation of occupancy patterns with electricity usage. The system's effectiveness in evaluating energy suitability and its potential to offer insights into consumption behaviors are essential facets of our investigation. By presenting a user-friendly interface that conveys real-time occupancy data and energy consumption metrics, we aim to empower users with the knowledge and tools needed to make informed decisions for energy optimization. As we delve deeper into the details of our methodology and findings, this study seeks to shed light on the transformative potential of integrating technology and data-driven insights to forge a sustainable and energy-efficient future.

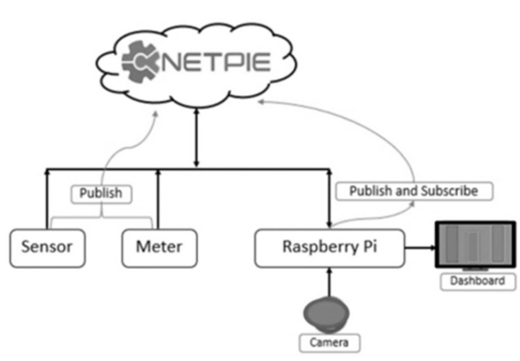

Fig.1. System architecture

Method

We employed motion sensors, a Raspberry Pi with a camera, and the NETPIE platform [9] to create a system for real-time occupancy monitoring and energy optimization. The method of this work is presented in Figure 1.

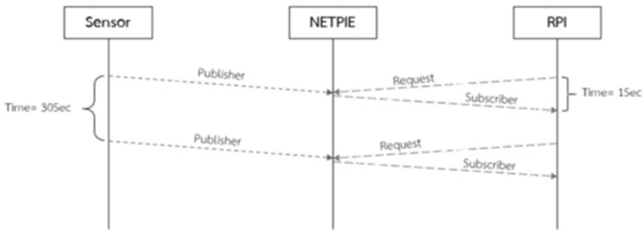

Fig.2. System timing diagram

A face detection algorithm identified occupants from camera footage. Occupancy data was sent to NETPIE for analysis. Correlating occupancy with electricity usage allowed us to calculate a percentage-based energy suitability indicator. We conducted real-world tests to assess the system's accuracy and insights into energy patterns. This integrated approach offers a promising solution to energy issues, aiding informed decision-making for enhanced energy efficiency and sustainability.

Figure 2 shows the system timing diagram. The sensor periodically transmits data to the NETPIE platform over the internet network, doing so at 30-second intervals to provide supplementary information. Simultaneously, an electric meter gauges the room's electrical energy consumption and conveys this information to NETPIE. For instance, a Raspberry Pi queries NETPIE for data from factory sensors. These sensors supply essential information for external monitoring. The Raspberry Pi utilizes its camera to capture images of individuals, subsequently analyzing the count of occupants. If there is a substantial number of individuals present, the system's dashboard compiles data regarding energy suitability.

Multi Sensors

A Multi sensors [7], encompassing the DHT22, motion sensor, and LDR light sensor, have been incorporated into the system. These sensors interface with an ESP8266 microprocessor, adeptly capturing both analog and digital data readings, which are subsequently transmitted to the device. Notably, these sensors can be seamlessly integrated with NETPIE for further data processing and analysis. The device's programmability is facilitated through the utilization of the Arduino programming language. A visual representation of this device configuration is depicted in Figure 3.

Fig.3. Multi sensors hardware

Energy Meter

The energy meter, specifically the PZEM-004T [10] module coupled with a current transformer (CT), serves as the primary tool for quantifying electrical energy consumption. The device's programmability leverages the ESP8266 microcontroller, allowing for custom configurations. Both of these devices underwent rigorous installation procedures, meticulously assessing their reliability, power measurements, power factor accuracy, and overall performance. Significantly, the device's placement at the main breaker within the room enables a comprehensive evaluation of the aggregate electrical consumption. The installation process is elaborated upon in two key points: the first highlights the wiring connection with the CT, while the second delineates the placement of the energy meters. The meter is shown in Figure 4.

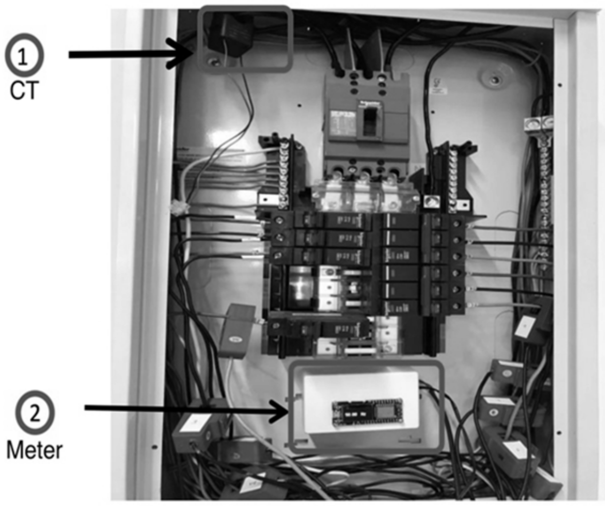

Fig.4. Energy meter installation

Raspbery Pi-based Energy Analysis

The Raspberry Pi-based Energy Analysis system is tasked with the evaluation of electrical energy consumption data and capturing images of individuals within a room to assess energy suitability. The hardware configuration comprises a Raspberry Pi 3B+ and a Logitech 720P camera. This integrated system possesses the capability to conduct comprehensive analysis of electrical energy utilization patterns.

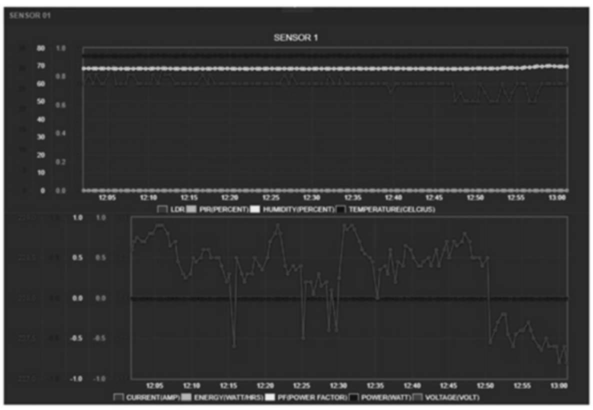

Fig.5 Sensors information display in a user interface

Figure 5 displays a real-time graph depicting sensor data alongside electrical energy consumption values. The sensors incorporated in this illustration encompass measurements of light intensity, human motion detection, relative humidity, and temperature, presented in their respective categories. Once data has been collected from the sensors and meters, the subsequent step involves utilizing a Raspberry Pi for image analysis, specifically for detecting the number of individuals within a room and presenting the energy suitability results through a dashboard. An illustrative example of this data processing is depicted in Figure 6.

Fig.6. Data processing via Raspbery Pi

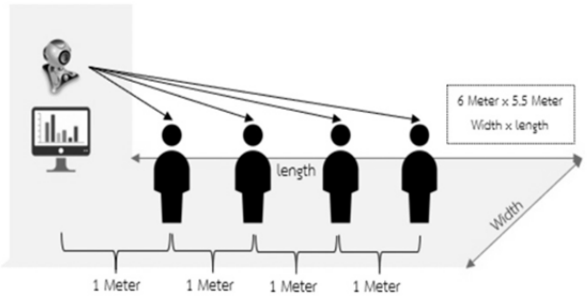

Fig.7. experimental tests diagram

Fig.8. Three scienario for person capture at a distance of 1 meter

Accuracy Testing of Image individual Person

This section pertains to the testing of accuracy in capturing individuals within a room using three different experimental scenarios: direct facial recognition, facial recognition with the inclusion of eyeglasses, and facial recognition with the addition of headwear. Additionally, the precision of these methods is assessed at varying distances from the camera.

Figure 7 and 8 illustrate set of experimental tests conducted at a distance of 1 meter from the camera across three distinct scenarios. These experiments aimed to evaluate the system's performance and accuracy under varying conditions, focusing on the different facial recognition scenarios as specified.

In the first scenario (direct facial capture), the system achieved flawless facial recognition accuracy within the 1-2 meter range but exhibited a single failure at 3-4 meters and two failures at 5 meters. This highlights the system's sensitivity to distance in this context. In the second scenario (wearing eyeglasses), the results showcased exceptional accuracy at 1 meter but gradually deteriorated with increased distance. One failure occurred at 2 meters, two at 3-4 meters, and three at 5 meters. These findings emphasize the impact of both distance and eyeglasses on accuracy, particularly at longer ranges. In the third scenario (wearing headwear), accuracy diminished significantly as distance increased. At 1 meter, two failures were observed, while at 2-3 meters, three failures occurred, escalating to four failures at 4 meters. At the farthest distance of 5 meters, the system failed in all six attempts. This underscores the substantial challenge posed by headwear, coupled with distance, for the facial recognition system. Overall, these experiments highlight the complex interplay between distance and various scenarios on facial recognition accuracy. While direct facial capture showed high accuracy at closer ranges, wearing eyeglasses and headwear negatively impacted accuracy, particularly at longer distances. These findings are crucial for developing and optimizing facial recognition systems in real-world applications. Based on the provided data, a summary can be presented in Table 1:

Table 1. Accuracy summarizes the facial recognition finding

Scenario	Distance Range (meters)	Failures (out of 6 attempts)
Direct Facial Capture	1-2	0
	3-4	1
	5	2
Wearing Eyeglasses	1	0
	2	1
	3-4	2
	5	3
Wearing Headwear	1	2
	2-3	3
	4	4
	5	6

Energy Suitability

Based on the previous energy measurements, energy consumption was assessed in terms of energy per hour (Watt-Hours), where 1,000 watts equates to 1 unit. It was determined that each individual consumes approximately 2 units of electricity per day (83 Watt-Hours). In the context of our classroom experiment, it was observed that the room can comfortably accommodate around 20 individuals. Consequently, the following equation can be derived [5]:

$$S_E = n_p \times \frac{20\times 83}{E} \times \frac{100}{20} \tag{1}$$

$$S_E = n_p \times \frac{1660}{E} \times 5 \tag{2}$$

Where: S_E - Energy suitability (%); n - Number of people; E - Amount of electicity currently (Wh)

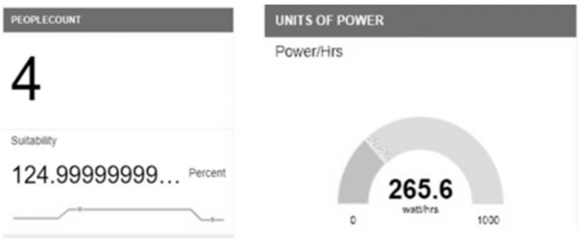

Fig.9. The visual representation of Energy performance-related the user interface

As depicted in Figure 9, the first section of the user interface (UI) is capable of accurately counting the number of individuals in the room, yielding a total count of 4 individuals. The second section of the UI displays the computed energy suitability, which stands at 124.9%. Lastly, in the third section, the electricity consumption is indicated at 265.6 watts per hour.

$$S_E = \frac{4 \times 1660 \times 5}{265.6} = 125\%$$

Conclusion

In summary, our study focused on energy monitoring and occupancy analysis using a Raspberry Pi-based system. We quantified energy consumption in watt-hours, with each person averaging 83 watt-hours per day. Through experiments, we assessed the system's accuracy in detecting individuals at varying distances and under different scenarios. Notably, the system achieved optimal accuracy at shorter distances and when individuals were not wearing eyeglasses or headwear. The user interface showcased real-time occupancy data, energy suitability percentages, and electricity consumption rates. These findings provide valuable insights into optimizing energy usage based on occupancy, offering potential applications for enhancing energy efficiency in various settings. Future work should explore advanced machine learning algorithms to enhance facial recognition accuracy, especially in scenarios involving eyeglasses or headwear. Additionally, investigating the integration of occupancy-based energy optimization into smart building management systems for real-world implementation is a promising avenue for future research.

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