Grenze International Journal of Engineering and Technology, January Issue

Real-Time Energy Monitoring and Automation System using ESP32 and IoT

Ralieka Mishra[1], Sohan Anand Fulzele[2], Arjun Sandeep Jadhav[3], Alok Dayaram Thakare[4], Ninad Dinesh Shegokar[5] and Pallavi Devendra Deshpande[6]
[1-5]Electronic and Telecommunication, Vishwakarma Institute of Information Technology, Pune, India
Email: ralieka.22310537@viit.ac.in, sohan.22310010@viit.ac.in, arjun.22310687@viit.ac.in, alok.22310171@viit.ac.in, ninad.22310638@viit.ac.in
[6]Asst. Professor, Electronic and Telecommunication, Vishwakarma Institute of Information Technology, Pune, India
Email: pallavi.deshpande@viit.ac.in

***Abstract*— This paper presents a novel design for an integrated energy monitoring and automation system, tailored for smart home applications. The system utilizes a current sensor along with an ESP32 microcontroller to monitor energy consumption and incorporates a PIR sensor for automated light control based on room occupancy. Energy data is logged and analyzed in real time using ThingSpeak, offering a simple yet effective platform for data acquisition and visualization.**

***Index Terms*— Energy meter, Automation, IOT, Smart Home, ACS712, ESP32, PIR sensor, ThingSpeak.**

I. INTRODUCTION

In today’s fast-paced world, energy consumption has significantly increased due to rapid urbanization, growing populations, and the widespread use of technology-based devices. This surge in demand has placed immense pressure on existing power infrastructure, making energy conservation more critical than ever. Energy monitoring systems have emerged as an effective solution, enabling real-time tracking, intelligent management, and optimization of electricity consumption across residential and commercial environments. These systems are becoming a central part of the growing Internet of Things (IoT) revolution, which connects smart meters, appliances, and energy grids, leading to smarter, more efficient homes and workplaces.

This paper presents a smart energy system that combines real-time energy monitoring with home automation, utilizing an LED for a straightforward yet effective demonstration. The system integrates an ACS712 current sensor with an ESP32 microcontroller to monitor energy consumption, logging data on the ThingSpeak platform for real-time analysis.

Additionally, the design features a PIR sensor for automated lighting control based on room occupancy, thereby enhancing both energy efficiency and user convenience.

By incorporating wireless technologies and automation, this system offers a cost-effective, scalable solution for energy metering and automation, with the potential for future expansion and integration of more advanced functionalities. The following sections review the evolution of IoT-based energy monitoring systems, focusing on design, implementation, and real-world applications that aim to reduce energy wastage, automate appliance control, and optimize power distribution.

Grenze ID: 01.GIJET.11.1.527_3

II. RELATED WORK

IoT-Based Energy Monitoring System

The growing importance of energy monitoring systems is evident in their ability to digitize energy consumption data, making it accessible from any location. In recent years, energy monitoring systems based on IoT technology have significantly improved the ways in which consumers and industries track and control energy usage.

Tsyrulnyk et al. [1] developed an IoT-based energy monitoring system utilizing a WeMos wireless module with the ESP8266 microcontroller. The system integrates an ACS712 current sensor to measure energy consumption while isolating the load from the IoT module. It allows users to remotely monitor energy consumption and sends alerts when usage exceeds predefined thresholds. However, it lacks advanced analytics and predictive maintenance features, limiting its functionality for large-scale energy management.

Similarly, Hartman et al. [2] proposed a low-cost energy monitoring system that integrates IoT with traditional home appliances. Their system uses Raspberry Pi nodes and cloud-based databases to track energy consumption and control devices like lighting and air conditioning. While effective for remote appliance control, the system does not provide energy forecasting or detailed load analysis, which could improve optimization efforts.

Energy Conservation and Automation

Energy wastage due to human error, such as leaving devices on unnecessarily, has been a long-standing issue.

Padmini et al. [3] developed an IoT-based automation system that controls appliances based on room occupancy. Their solution automatically adjusts lighting and other appliances, reducing unnecessary energy use. However, it relies primarily on motion sensors, which may not accurately detect all situations, such as stationary occupants.

Rahman et al. [4] extended this concept by introducing the Voice Command Automation System (VCAS). Their system integrates IoT with voice-activated controls, allowing users to operate appliances via voice commands. This approach improves accessibility but is prone to potential issues in noisy environments or when voice recognition fails, reducing overall reliability.

Smart Energy Meters and Fault Detection

Smart energy meters play a crucial role in modern energy management by providing real-time data and enabling better load control.

Avancini et al. [5] introduced an IoT-based smart metering system that supports two-way communication with the energy grid, enhancing load balancing and demand-side management. However, the lack of integration with renewable energy sources limits its applicability in smart homes relying on solar or wind energy.

Varshney et al. [6] developed an IoT-based fault detection system for home automation devices. Their system monitors power consumption patterns to detect issues like leakage currents that could result in higher electricity bills or pose safety risks. While effective for fault detection, it is focused on small-scale automation systems and may require modifications for larger or commercial setups.

Optimizing Energy Use in Smart Homes

The integration of Home Energy Management Systems (HEMS) with IoT has become essential for optimizing energy use in households. Ma et al. [7] proposed a HEMS model that manages distributed energy sources, such as solar panels, alongside conventional power supplies. Their system provides consumption insights based on fluctuating tariffs, enabling users to minimize costs. However, its complexity may pose challenges for non-technical users during setup and operation.

Similarly, AL Sultan et al. [8] introduced a multi-agent IoT-based energy management system that coordinates household appliances based on real-time power demand. Their solution improves peak load management by distributing energy usage efficiently, reducing the risk of grid overload. However, it requires continuous internet connectivity, which could affect performance in remote areas with unstable networks.

Emerging Trends in IoT-Based Energy Management

The need for scalable and flexible energy management solutions continues to drive research in this area.

Saleem et al.

[9] proposed a Smart Energy Management System (SEMS) that integrates IoT with smart meters to monitor energy use at both device and network levels. Their system allows for non-intrusive load monitoring and demand-side management, promoting energy conservation in large facilities. Despite its advantages, the system's scalability in highly complex environments remains a challenge.

Lastly, Hiwale et al. [10] explored the use of IoT platforms like ThingSpeak to provide real-time energy data analytics. Their system uses Arduino microcontrollers with Wi-Fi modules to transmit energy usage data to a web platform. While this solution offers comprehensive data visualization, it requires continuous cloud access, which may limit its reliability during network outages.

The existing literature emphasizes the importance of combining IoT technologies with energy monitoring and automation to achieve efficient energy management. While several studies have explored the use of sensors, microcontrollers, and wireless technologies, challenges remain in terms of scalability, advanced analytics, and seamless integration with renewable sources.
Building on these insights, our project focuses on developing a smart energy system using the ESP32 microcontroller, ACS712 current sensor, and PIR sensor. This system automates lighting based on occupancy detection and logs real-time data to the ThingSpeak platform, offering a practical demonstration of energy conservation through automation. The simplicity of the design ensures scalability and flexibility, with potential for future upgrades to enhance functionality and analytics.
We referred to the work of Pallavi Deshpande et al. [11] & [12] to guide the structure, format, and flow of this paper for conference publication. While their studies informed our organizational approach, no direct co

III. Methodology

A. System Overview

The proposed smart energy system integrates two primary functionalities: energy monitoring and automation. These are combined into a single platform to optimize energy consumption through real-time tracking and intelligent control of devices, demonstrated using an LED.
The system is powered by the ESP32 microcontroller, which acts as the central processing unit, facilitating communication between the sensors and the ThingSpeak platform for data logging and visualization.
For energy monitoring, an ACS712 current sensor is employed to measure the current flowing through the load. The ESP32 collects this data and calculates energy consumption over time.
This data is sent to ThingSpeak via Wi-Fi for real-time visualization, allowing users to monitor energy usage remotely.
Automation is achieved through a PIR sensor, which detects room occupancy and controls the lighting system. When motion is detected, the ESP32 triggers a relay to switch the LED on or off, reducing unnecessary energy usage. The ESP32 powers the entire system, providing the required voltages to the sensors and the relay.
This integration of energy monitoring, automation, and real-time data logging on ThingSpeak offers a practical, efficient solution for smart home energy management.

B. Components Used

- ESP32: The ESP32 serves as the core of the system, managing sensor input and controlling automation processes. Its built-in Wi-Fi capability allows for seamless data transmission to ThingSpeak for real-time monitoring. The ESP32 was selected for its low power consumption, flexibility, and ease of integration with IoT platforms.
- ACS712 Current Sensor: The ACS712 is a Hall-effect-based sensor used to measure both AC and DC current. In this project, it monitors the current drawn by the LED, providing the ESP32 with data needed to calculate energy consumption. The sensor’s output is proportional to the current, making it a reliable tool for energy monitoring.
- PIR Sensor (HC-SR501): The PIR sensor detects human presence by sensing motion in the room. When movement is detected, the PIR sends a signal to the ESP32 to control the relay and LED. This ensures that lighting is only activated when necessary, contributing to energy savings.
- Relay Module: A 5V single-channel relay is used to control the LED based on the ESP32’s signals. The relay serves as a switch, allowing low-voltage signals to control the high-voltage LED, ensuring safe and efficient operation.
- LED: An LED represents the load in this project. Its current consumption is monitored by the ACS712, and its operation is controlled through the relay in response to occupancy detected by the PIR sensor. The LED simulates a real-world load, demonstrating the system's ability to monitor and control energy usage.
- Software:
    - ThingSpeak: ThingSpeak provides real-time data logging and visualization of energy consumption, allowing users to monitor and analyze energy usage remotely.
    - Arduino IDE: Used to program the ESP32, enabling data collection, automation control, and ThingSpeak integration.
    - EasyEDA: Utilized for circuit design and simulation, ensuring proper connectivity before physical implementation.

C. Circuit Design and Description

The system (as shown in Fig 1) is divided into two major subsystems: energy monitoring and automation. The energy monitoring circuit uses the ACS712 current sensor and the ESP32 microcontroller, while the automation circuit relies on a PIR sensor and relay to control the LED based on room occupancy.

Energy Monitoring Subsystem:

- ➢ Power Supply: The ESP32 is powered through a 5V USB connection, which also supplies power to the relay and LED. The ACS712 and PIR sensor are powered through the 3.3V pin of the ESP32.
- ➢ ACS712 Connection: The current sensor is connected in series with the LED to measure current. Its output is fed into an analog pin (GPIO33) on the ESP32 for current measurement.
- ➢ ESP32 Integration: ESP32 reads the current data from the ACS712 sensor and calculates power using:Power(W)=Voltage(V)×Current(A)

The data is then transmitted to the ThingSpeak platform for real-time visualization and analysis, enabling efficient energy management.

Automation Subsystem:

- ➢ PIR Sensor Setup: The PIR sensor is powered by the 3.3V output from the ESP32, with its output connected to GPIO27 on the ESP32. This setup allows the ESP32 to detect motion and control the LED based on room occupancy.
- ➢ Relay Control: The 5V relay module is used to switch the LED on or off. The relay's COM pin is connected to the ACS712 sensor's IP+ terminal, and its NO (normally open) pin is connected to the 5V power supply. When the PIR sensor detects motion, the ESP32 activates the relay (via GPIO26), turning the LED on. If no motion is detected, the LED automatically turns off.

ThingSpeak Data Logging: The ESP32 is connected to ThingSpeak, where the energy data from the ACS712 is logged in real-time. This allows the system to visualize energy consumption trends and monitor power usage. (Fig 2(a) and Fig 2(b)). All connections are integrated on a single breadboard for easy prototyping and testing. The sensors, relay, and ESP32 are neatly arranged, ensuring efficient and compact layout.
This system demonstrates a scalable and practical approach to smart energy management through the use of IoT technologies. The real-time monitoring and automation capabilities can be expanded for more complex loads and environments, providing a robust solution for future smart homes and buildings.

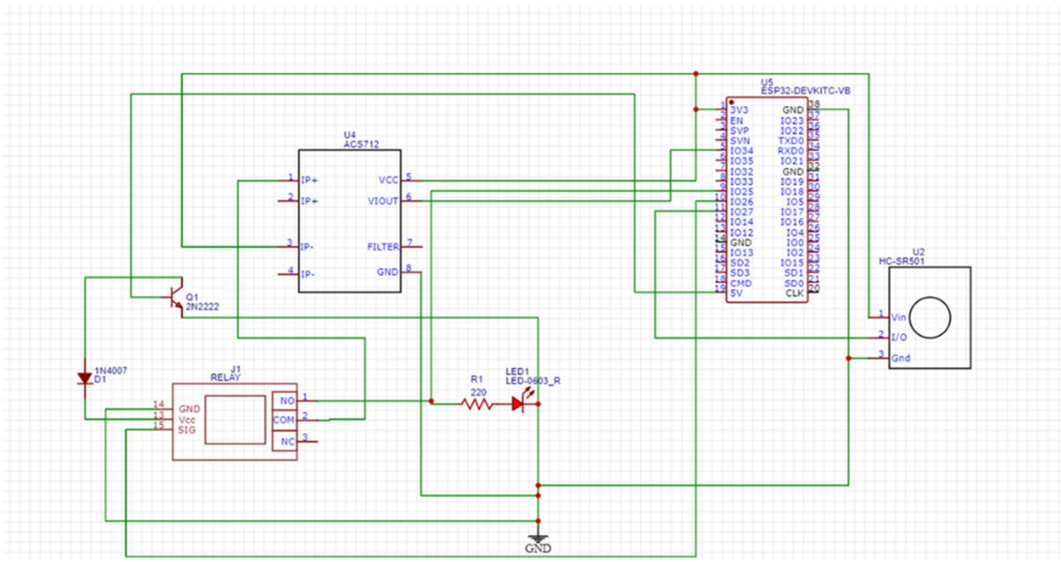

Fig 1. Circuit on EasyEDA

Software Design

Energy Metering Calculation

```
int currentSensorPin = 34; // ACS712 pin
float voltage = 5.0; // 5V fixed
float current = analogRead(currentSensorPin)*(3.3 / 4095.0); // Read and convert current
float power = voltage * current; // Power calculation
```

Explanation: This snippet reads data from the ACS712 current sensor via the analog input pin 34 on the ESP32. The sensor provides current values, which are then multiplied by a constant 5V to calculate the power consumption in watts. The result is sent to ThingSpeak for real-time monitoring.

PIR Sensor for Automation

```
int pirPin = 27; // PIR sensor pin
int relayPin = 26; // Relay control pin
void loop() {
  int motion = digitalRead(pirPin);
  if (motion == HIGH) {
    digitalWrite(relayPin, HIGH); // Turn on the LED
  } else {
    digitalWrite(relayPin, LOW); // Turn off the LED
  }
}
```

Explanation: This part of the code handles the automation process.

The PIR sensor checks for motion through the digital pin 27, and if motion is detected, the relay is triggered to power on the LED. If no motion is detected, the LED turns off automatically after a predefined time.

IV. Results and Discussion

The proposed smart energy monitoring and automation system was rigorously tested across multiple phases, focusing on calibration, automation performance, and energy-saving potential. Each component of the system was evaluated for accuracy, efficiency, and real-world applicability.

A. Energy Monitoring

Calibration of ACS712 Current Sensor:

The ACS712 current sensor was calibrated against a standard digital multimeter using various known loads, including resistive elements like bulbs and heaters. The results showed a deviation of less than 5% from the multimeter readings, indicating reliable performance for continuous energy tracking.

Data Logging and Communication

The ESP32 successfully collected real-time current and power consumption data from the ACS712 sensor.

(Fig 3(a) and Fig 3(b)).This data was transmitted to the ThingSpeak IoT platform via Wi-Fi, where it was stored and visualized without interruptions. The system's ability to log data remotely ensured seamless access for ongoing analysis and monitoring.

B. Automation Functionality

Occupancy Detection with PIR Sensor:

The PIR sensor was tested under controlled conditions to evaluate its responsiveness to human movement.

On average, the system activated the relay-controlled LED within 1.5 seconds of detecting occupancy and deactivated the LED after 3 seconds of inactivity.

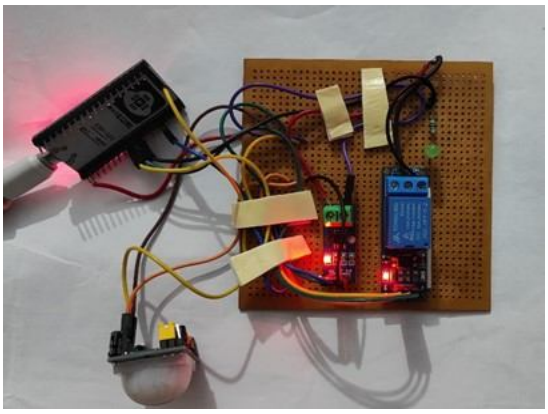

Fig 2(a). LED when motion is not detected

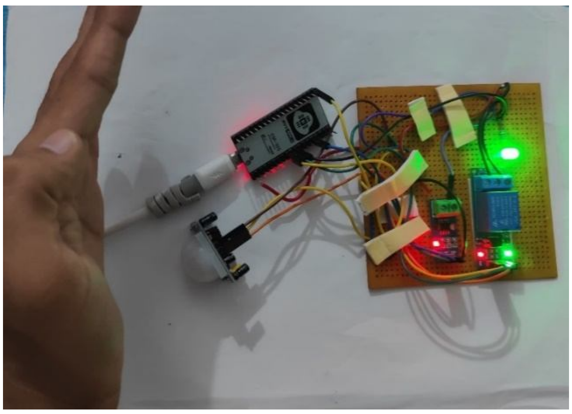

Fig 2(b). LED when motion is detected

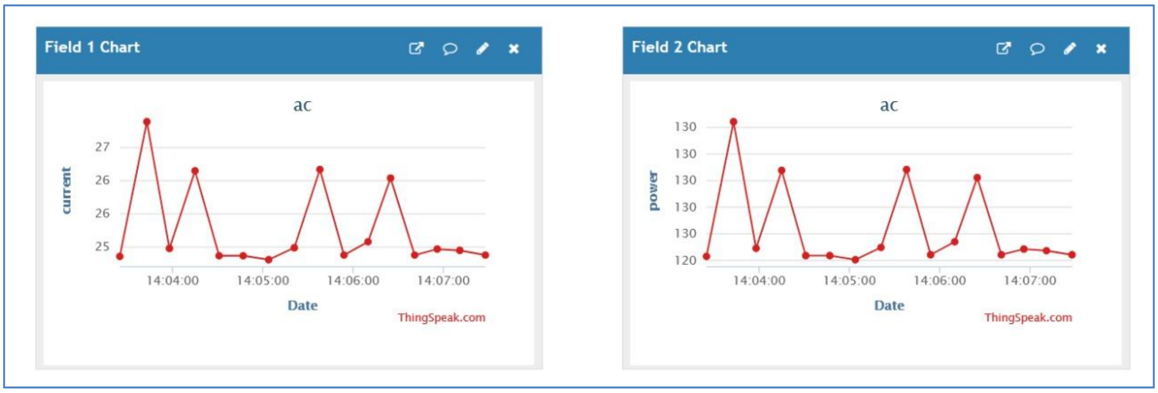

Fig 3(a). Visualization of current data on ThingSpeak

Fig 3(b). Visualization of current data on ThingSpeak

V. APPLICATIONS

The developed energy monitoring and automation system has a wide range of potential applications, including:

- Smart Homes: Automates lighting and monitors real-time energy consumption to provide insights and reduce bills.
- Commercial Buildings: Helps manage and optimize energy use across multiple offices or facilities.
- Industrial Settings: Tracks machinery energy usage and implements automated shutdown systems.
- Educational Institutions: Promotes energy conservation awareness among students and staff.
- Smart Grids: Integrates seamlessly with renewable energy sources.

VI. CONCLUSION AND FUTURE SCOPE

This project demonstrates the effective integration of IoT technology for energy monitoring and automation using the ESP32, ACS712 current sensor, and PIR sensor. The system not only provides accurate real-time energy usage insights through ThingSpeak but also optimizes energy consumption by automating lighting based on occupancy detection.

The results highlight the system's reliability in reducing unnecessary energy consumption, with significant potential for scalability in smart homes, commercial buildings, and industrial environments. Its cost-effectiveness and adaptability make it a practical solution for energy management across diverse applications.

This work underscores the growing importance of IoT in driving smarter energy solutions. The system can be implemented using a simple bulb and easily extended to control various home appliances, offering a practical solution for everyday energy management. Future enhancements could include incorporating renewable energy sources, advanced fault detection, or the use of machine learning algorithms to predict consumption trends and optimize energy usage further, paving the way for more sophisticated and sustainable energy systems.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to Vishwakarma Institute of Information Technology for providing the resources and infrastructure required for this project. Special thanks to our mentor, Dr Pallavi Deshpande for her invaluable guidance and support throughout the development and testing phases. We extend our heartfelt thanks to our peers for their encouragement and collaboration.

REFERENCES

[1] (Tsyrulnyk, 2022)S. Tsyrulnyk, V. Tromsyuk, M. Tsyrulnyk, and P. Rymar, “Energy Monitoring System based on IoT,” CEUR Workshop Proceedings, vol. 3039, pp. 1-7, 2022. Available: https://ceur-ws.org/Vol-3039/paper2.pdf

[2] (Hartman, 2019) W. T. Hartman, A. Hansen, E. Vasquez, S. El-Tawab, and K. Altaii, “Energy Monitoring and Control Using IoT System,” IEEE Internet of Things, 2019. Available: https://ieeexplore.ieee.org/abstract/document/8374723

[3] (Padmini, 2020)J. Jeya Padmini, A. Anie Selva Jothi, and R. Harikrishnan, “Automated Energy Conservation Techniques,”IEEEAccess,vol.8,pp. 182034-182045, 2020. Available: https://ieeexplore.ieee.org/document/88221400

[4] (Rahman, 2023) M. Rahman, A. Al Farabe, M. R. Al Islam, M. Rahman, and G. Ashraf, “Voice Command Automation System (VCAS) for Controlling Electrical Devices Using Arduino,” International Journal of Computer Science and Engineering, vol. 12, no. 3, pp. 1-8, 2023. doi:110.1007/978-981-19-9858-4_20.

[5] (Avancini, 2021) D. B. Avancini, J. J. P. C. Rodrigues, R. A. L. Rabêlo, A. K. Das, S. Kozlov, and P. Solic, "A new IoT-based smart energy meter for smart grids," International Journal of Energy Research, vol. 45, no. 9, pp. 13345-13358, 2021. https://onlinelibrary.wiley.com/doi/abs/10.1002/er.5177

[6] (Varshney, 2023) T. Varshney, K. Jaya Chitra, U. R. Danuwar, A. Raja, and S. M. Mohmed, "IoT Based Fault Detection on Appliances of Home Automation," International Journal of Advanced Research in Engineering Science andManagement,vol.6,no.5,pp.16,2023.https://www.ijaresm.com/uploaded_files/document_file/Dr._Tarun_Varshney_awvU.pdf

[7] (Ma, 2021) Y. Ma, X. Chen, L. Wang, and J. Yang, "Study on Smart Home Energy Management System Based on ArtificialIntelligence,"EnergyReports,vol.7,pp.128135,2021.Available:https://onlinelibrary.wiley.com/doi/10.1155/2021/9101453

[8] (Sultan, 2021) Y. Al Sultan, B. S. Salma, and B. A. Zafar, "Smart Home Energy Management System: A Multiagent Approach," International Journal of Innovative Technology and Exploring Engineering, vol. 12, no. 3, pp. 1-8, 2021. Available: https://thesai.org/Downloads/Volume12No3/Paper_29-Smart_Home_Energy_Management_System.pdf

[9] (Saleem, 2021) M. U. Saleem, M. R. Usman, and M. Shakir, "Design, implementation, and deployment of an IoT-based smart energy management system," in 2021 International Conference on Artificial Intelligence (ICAI), pp. 196-201, 2021. Available: https://ieeexplore.ieee.org/abstract/document/9395090

[10] (Hiwale, 2018) A. P. Hiwale, D. S. Gaikwad, A. A. Dongare, and P. C. Mhatre, "IoT Based Smart Energy Monitoring," International Research Journal of Engineering and Technology, vol. 5, no. 3, pp. 1-5, 2018. Available: https://www.irjet.net/archives/V5/i3/IRJET-V5I3579.pdf

[11] (Deshpande, 2019) P. D. Deshpande, P. Mukherji, and A. S. Tavildar, "An accurate hand-based multimodal biometric recognition system with optimized sum rule for higher security applications," International Journal of Biometrics, vol. 11, no. 3, pp. 222-242, 2019. doi: https://doi.org/10.1504/IJBM.2019.100830

[12] (Deshpande, Accuracy enhancement of biometric recognition using iterative weights optimization algorithm, 2019) P. D. Deshpande, P. Mukherji, and A. S. Tavildar, "Accuracy enhancement of biometric recognition using iterative weights optimization algorithm," EURASIP Journal on Information Security, vol. 6, 2019. doi: https://doi.org/10.1186/s13635-019-0089-z