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Energy-Efficient TRIZ-Inspired Paradigm to Automate Consumer Electronic Devices

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Abstract: The ubiquitous problem of electrical energy waste is driven by human error, in which people regularly forget to turn off appliances when they leave a room, resulting in excessive consumption. The paper presents an energy-efficient TRIZ-inspired (EETRIZ) paradigm to automate consumer electronic devices in order to address this problem. Employing motion detection at entry and exit points, the system discerns room occupancy, effectively managing electrical appliances like lamps, fans, and air conditioners. The integration of theory of inventive problem solving (TRIZ) principles guides the ideation and design of an efficient switching mechanism. The system demonstrates that it is flexible by controlling multiple electronic consumer devices simultaneously. This paradigm can be used in a variety of environments, such as homes, offices, schools, and universities, and its goal is to reduce excessive energy use that results from human negligence. With an emphasis on economic viability and environmental impact, the proposed EETRIZ paradigm not only offers enhanced energy efficiency but also lays the groundwork for long-term sustainability practices, aligning with global efforts towards greener and smarter energy management. The proposed EETRIZ is implemented on C platform with support of MPLAB, Nuvoton 8051 Serie MCU Programming, GMPLibrary (GMP-5.1.1) and, Miracl Library. The proposed EETRIZ outperforms current state-of-the-art methods in terms of energy efficiency, cost-effectiveness, precision, and user-friendliness, according to hardware testing.

Keywords: automated switching system; motion detection; TRIZ principles; energy efficiency; smart energy management

1. Introduction

The rising cost and demand for energy has necessitated the development of novel systems for energy monitoring, control, and conservation. Furthermore, it reveals that energy mismanagement accounts for 20% of all energy losses [1]. As a result, the use of energy management can make a significant contribution to minimizing wasteful energy consumption. Efficient electrical energy utilization is paramount in contemporary society, with a growing emphasis on mitigating wastage resulting from human oversight [2]. The habitual neglect of turning off appliances upon exiting a space significantly contributes to unnecessary power consumption, highlighting the need for innovative solutions. This research addresses this prevalent challenge through the proposition and implementation of an automated system guided by the principles of TRIZ. The central issue revolves around individuals leaving electrical appliances operational in unoccupied spaces, escalating energy bills and hindering sustainable energy practices. In response, our study introduces a EETRIZ system designed to effectively curtail such energy wastage. The proposed system relies on sophisticated motion detection mechanisms strategically placed at entrance and exit points. By discerning the real-

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time occupancy status of a room, the system orchestrates precise control of various electrical appliances, including lighting, fans, and air conditioning units [3]. A critical aspect of our approach lies in integrating insights derived from TRIZ principles, injecting a systematic and inventive methodology into the design process. Versatility is a hallmark of the implemented system, adeptly managing simultaneous activation and deactivation of multiple appliances based on detected occupancy [4]. This adaptability extends the system's applicability to diverse settings, spanning residential spaces, offices, educational institutions, and more. Beyond mere automation, the system provides users with real-time feedback displayed on a dedicated screen, empowering them to actively monitor and optimize electricity usage. This feature fosters a shift towards smarter and more sustainable energy consumption practices [5]. As we delve into the intricacies of our EEITRIZ system, this paper elucidates the methodology, design considerations, and the underlying technological components. The effective facility management within buildings is intrinsically tied to the pursuit of energy conservation, a critical facet in achieving cost-efficient operations. The allocation of electrical energy within structures is a complex balance, with lighting and heating, ventilation, and air conditioning (HVAC) systems constituting significant contributors [6]. With a rising population, global economic growth is booming. This will result in increased electricity demand in the future. Furthermore, building energy consumption is deemed the principal energy consumer, with a significant percentage of energy wastage due to poor management and ineffective strategy implementation. Global energy consumption is now increasing at a 2.9% annual rate, and this rate is expected to accelerate in the coming years. Notably, due to patterns in developing countries' economic growth, Asian regions are presently consuming more power than the United States of America [7]. In the United States, the energy footprint of lighting alone reaches 10% of total electricity consumption, while HVAC systems claim over 40% in both residential and commercial spaces. Notably, European countries expend a remarkable 76% of their electrical energy on HVAC systems to maintain optimal indoor conditions. The education sector, as a substantial consumer of electrical energy, emphasizes the widespread impact of inefficient energy management, accounting for 21% of the total consumption in the United States in 2022 across primary schools, middle schools, high schools, colleges, and universities [8,9]. Despite advancements in technology aimed at minimizing power consumption, the persistent issue of electricity wastage arises when electrical devices, such as lighting and HVAC systems, are left operational in unoccupied spaces due to human negligence. The intricate interplay between occupant presence and building energy consumption is well-documented, with studies revealing that careless user behavior can significantly compromise a building's energy efficiency, potentially accounting for up to one third of energy waste. This underscores the urgency for innovative solutions that autonomously address the challenge of energy wastage arising from human neglect [10]. To address this pressing challenge, this research advocates for the implementation of proactive and autonomous energy-saving initiatives. A pivotal focus of the study is the development of a smart automatic electric appliance activation system that seamlessly integrates with existing power infrastructures. This innovative system leverages cutting-edge technology to facilitate automatic activation and deactivation of electrical appliances based on real-time occupancy data. The system incorporates a sophisticated counting capability to accurately determine the number of occupants in a room, enabling precise and responsive control. By addressing the inherent issues associated with smart sensing of human motion detection, particularly the need for continuous motion, the proposed solution not only minimizes unnecessary energy consumption but also ensures a user-friendly and seamless experience. This research extends beyond the immediate context of energy conservation to underscore the critical role of automation and motion detection in optimizing energy usage within built environments. The proposed system emerges as a sophisticated solution, offering a harmonious blend of efficiency and user-centric functionality. By bridging the gap between technological innovation and practical energy management, this study contributes to the broader discourse on sustainable and intelligent building practices.

Figure 1 illustrates the integration of smart technology to enhance energy efficiency in building management. The flowchart begins with the importance of facility management, emphasizing energy conservation as a key objective. It then details the allocation of electrical energy in buildings, highlighting the significant contributions of lighting and HVAC systems. The challenges associated with electrical energy wastage due to human negligence are depicted, leading to the proposed solution of smart electrical appliance activation system. This system seamlessly integrates with existing power systems, utilizing cutting-edge technology, including passive infrared sensors, to enable automatic control of electrical appliances based on real-time occupancy data. The flowchart further outlines how the system addresses smart sensing challenges and concludes with a call to action, advocating for proactive and autonomous energy-saving initiatives.

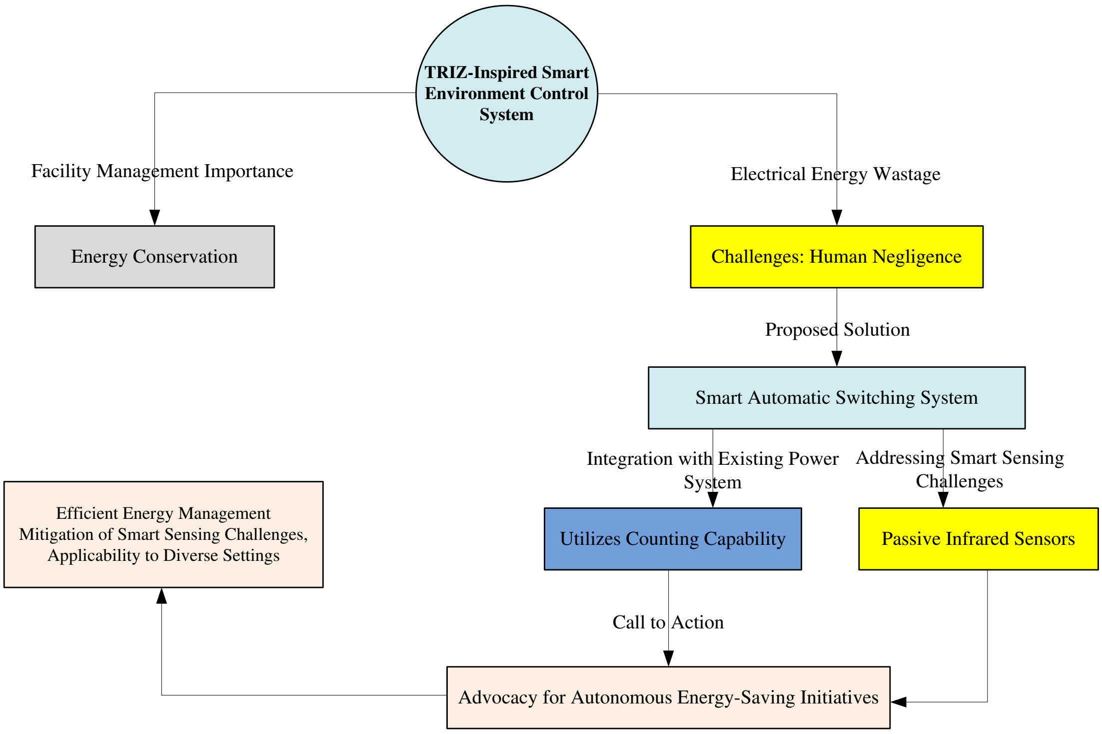

Figure 1. Smart technology integration for energy efficiency enhancement.

1.1. Research Contribution

This research makes several noteworthy contributions to the fields of facility management, energy conservation, and smart technology integration as follows:

- Innovative smart consumer electronic device activation system is introduced that seamlessly integrates with existing power systems. This system leverages cutting-edge technology, including passive infrared sensors, to enable automatic control of consumer electronic devices based on real-time occupancy data.
- The proposed EETRIZ contributes to efficient energy management. The counting capability is incorporated into the system to ensure the precise control, allowing consumer electronic devices to activate or deactivate based on the presence or absence of occupants in a room.
- The continuous motion is required for smart sensing that has been attained by employing the passive infrared sensors, which eliminates the need for sustained movement, enhancing user-friendliness and minimizing unnecessary energy consumption.
- The EETRIZ is a proactive and provides automation that helps to improve energy efficiency, cost-effectiveness, precision and user-friendly operation.

These contributions collectively advance the discourse on intelligent practices, offering a tangible solution to a prevalent issue while encouraging a broader consideration of autonomous energy-saving technologies.

1.2. Paper Organization

The organization of this paper is structured to provide a comprehensive exploration of the proposed smart electrical appliance activation system based on automatic switching system and its implications for energy efficiency management in Section 1 and Section 2 delves into related work, offering insights into existing research and technologies in the realm of automated systems and energy conservation. Section 3 details the research methodology employed in developing the proposed system, elucidating the integration of TRIZ principles and motion detection technology. Section 4 provides an in-depth exposition of the proposed approach for EETRIZ system, outlining its design and functionality. Following this, Section 5 presents the experimental configuration results, offering a quantitative assessment of the system's efficacy. Section 6, discussion of results and Section 7, concludes the paper, summarizing the key contributions and emphasizing the significance of the proposed solution and future work.

2. Related Work

The literature reveals significant strides in utilizing passive infrared sensors for environmental control, particularly in the activation of lighting systems based on the detection of human presence (Laha et al, 2022) [11]. Previous studies demonstrate the efficacy of PIR sensors equipped with trigger circuits in switching lights on or off upon detecting individuals (Jose, Malekian, 2017) [12]. Another line of research explores systems capable of recognizing people within enclosed spaces and dynamically adjusting lighting accordingly (Simeon et al, 2018) [13]. Further investigations extend the scope, aiming to accurately locate human presence using diverse techniques (Gou et at, 2023) [14]. However, a research gap is discerned from this body of work, specifically related to triggering multiple power supplies based on a predetermined number of people and concurrently providing real-time counting capabilities (Rabbani, Yee, 2022) [15].

Existing research, as exemplified in the works of (Ogenyi et al, 2019) [16] faces limitations in accurately detecting individuals wearing black uniforms due to light absorption issues. To address these shortcomings and bridge the identified research gap, this study proposes a novel smart electrical appliance activation system. Unlike previous systems, this solution autonomously counts the total number of people in real-time, enabling the triggering of multiple power supplies based on predetermined thresholds. The system employs a passive infrared sensor to calculate the total number of people entering and leaving a space (Hassani et al, 2020) [17], offering an intelligent and energy-efficient approach to appliance activation. Importantly, this method eliminates the need for continuous human movement to sustain appliance operation, contributing to both energy conservation and intelligent management of electrical appliances. To systematically approach the design and innovation of the proposed system, the research leverages the theory of inventive problem solving," commonly known as TRIZ. This problem-solving tool is integrated into the methodology to foster creativity and guide the ideation process for a cost-effective and efficient smart electrical appliance activation system (Chong et al, 2022) [18]. This approach adds a novel dimension to existing research by incorporating TRIZ principles into the design process, enhancing the potential for inventive and effective solutions in the realm of home and office automation. Table 1 presents a side-by-side examination of existing approaches and our innovative EETRIZ system. It succinctly highlights essential features, limitations, and distinctive solutions provided by our proposed system. Emphasizing its core strengths, it underscores the autonomy of counting, real-time activation functionalities, and the integration of TRIZ principles. These aspects collectively position our system as an advanced solution, marked by efficiency, responsiveness, and a strategic approach to creative problem-solving.

Table 1. Existing approaches vs. proposed EETRIZ system.

Approaches	Proposed Solutions	Features/Characteristics	Limitations
Laha et al. [11]	PIR Sensors for lighting systems and activation of lighting based on human presence	Efficacy of PIR sensors with trigger circuits.	Limited effectiveness in situations with minimal or sporadic movement.
Simeon et al. [12]	Systems for recognizing people and dynamic adjustment of lighting in enclosed spaces	Capability to recognize people within enclosed spaces.	Challenges in highly crowded or cluttered environments, potential privacy concerns.
Gou et al. [13]	Accurate human presence detection and locating human presence using diverse techniques	Extends scope to accurately locate human presence and various techniques explored	Limited to sensitivity to environmental factors like shadows or obstructions, potential cost implications.
Rabbani, Yee. [15]	Triggering power supplies based on people count and real time counting capabilities	Addresses the research gap of triggering multiple power supplies based on the count of people	Limited to reliability dependent on the accuracy of counting mechanisms, potential issues in highly dynamic environments.
Ogenyi et al. [16]	Limitations in detecting individuals and detection issues with individuals wearing black uniforms	Faces challenges in accurately detecting individuals in black uniforms due to light absorption issues.	Limited applicability in scenarios where individuals wear dark clothing, potential need for additional sensor technologies.
Hassani et al. [17]	Real-time counting for triggering power supplies	Autonomously counts total people in real-time, triggering power supplies based on predetermined thresholds.	Dependency on sensor accuracy, potential challenges in distinguishing between individuals in close proximity or rapid movements.
Chong et al. [18]	Methodology integration for design and innovation	Innovative approach counting people in real-time for triggering power supplies based on predetermined thresholds.	Limited to complexity in applying TRIZ principles, potential resistance to change in adopting inventive problem-solving methodologies.
Our proposed EETRIZ system	EETRIZ system integration proposes smart electrical appliance activation system, real-time counting for triggering power supplies	Integrates TRIZ into the methodology for inventive and effective solutions in smart electrical appliance activation system design.	Utilizes TRIZ for systematic ideation and innovation which contributes to energy saving and efficient resource use.

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3. Research Methodology

Our research methodology is rooted in the systematic integration of the theory of inventive problem solving into the development of an innovative smart electrical appliance activation system, emphasizing the significance of human motion detection for heightened automation efficiency. The TRIZ serves as a guiding framework for fostering creative ideation and innovation throughout the design process. At the core of our approach is the strategic incorporation of TRIZ principles during the ideation stage. This involves applying mathematical equations and algorithms to address challenges systematically. The primary algorithm utilized is the problem formulation algorithm. Equation (1) serves as the foundational cornerstone, embodying the conceptual framework that intricately weaves together the challenges confronted, the wealth of available resources, and the overarching goals. This equation encapsulates the dynamic relationship between these essential elements, forming the bedrock for generating inventive solutions. It elegantly symbolizes the interplay between identified challenges, the array of resources at our disposal, and the aspirational goals that collectively propel our pursuit of innovation. As we delve into the depths of this equation, we unravel the intricate tapestry of problem-solving, leveraging resources creatively to surmount challenges and steer towards the realization of overarching goals. This conceptual framework not only forms the basis of our research but also serves as a guiding beacon, illuminating the path towards inventive solutions that address real-world complexities with ingenuity and effectiveness.

$$I_s = \mathrm{f}\{C_h, R_{e,} G, \alpha, \beta, \gamma, \Delta\} + \sqrt{\frac{\sum_{i=1}^{n} X_i^2}{\psi}} \quad (1)$$

Where I_s denotes to inventive solution, f represents function, C_h denotes Challenges, $R_{e,}$ representing resources and G denotes goals, α: Represents a parameter capturing the temporal dynamics, emphasizing how the inventive solution evolves over time in response to changing conditions, β signifies a parameter associated with spatial considerations, capturing the distribution of challenges and the utilization of resources across different segments of the system, γ introduces a parameter reflecting adaptability, showcasing how the inventive solution adjusts to varying environmental conditions, Δ represents a parameter influencing decision-making, capturing the external influences and contingencies that may affect the success of the inventive solution and the term $\sqrt{\frac{\sum_{i=1}^{n} X_i^2}{\psi}}$ encapsulates the sensitivity and response of the inventive solution, reflecting its ability to adapt and make decisions based on the collective impact of various parameters. It provides a more nuanced and detailed perspective on the inventive solution, showcasing its multifaceted approach to address challenges, leverage resources, and achieve specific goals within the context of energy management in smart appliance systems. The challenge refers to the obstacles, problems, or issues that need to be addressed. These are the inefficiencies, limitations, or barriers hindering our process or system. The challenge is our research is the wastage of electrical energy due to human negligence in turning off appliances. Resources encompass the tools, technologies, methodologies, and other elements available to tackle the challenges. In the context of our paper, resources include the use of PIR, advanced automation technologies, and the principles derived from TRIZ and the goals represent the overarching objectives or desired outcomes. These are the targets that the inventive solution aims to achieve. As the goal is to develop an intelligent system that minimizes energy wastage by autonomously managing electrical appliances based on real-time occupancy data. Let's consider the challenge of energy wastage due to human negligence. The resources available include PIR sensors, automation technologies, and TRIZ principles. The goal is to create an efficient and sustainable system for managing electrical appliances. Therefore, the inventive solution involves designing a smart electrical appliance activation system that utilizes PIR sensors for real-time occupancy detection, integrates TRIZ principles for systematic problem-solving, and aims to reduce energy wastage by automatically controlling appliances based on occupancy.

In the context of our innovative energy management system, Equation (2) finds profound significance. Considering the real-world contradiction, we encounter; the need to minimize energy wastage versus the imperative of ensuring user convenience. This quandary often plagues traditional energy systems, where the challenge lies in striking a delicate balance between conserving energy resources and providing a seamless user experience. Where the contradiction matrix C_m becomes our guiding beacon. The function f_{TRIZ} orchestrates a meticulous analysis of the contradiction C_t arising from energy conservation challenges C_t, delicately weighed against an array of pertinent parameters P_r. Now, let's break down the components of the equation within this practical scenario:

$$C_m = f_{TRIZ}\left\{\frac{C_t}{\sqrt{\alpha}}.\left(\frac{P_r}{\beta}+\frac{\gamma}{\delta}\right)\right\} \tag{2}$$

Where C_m symbolizes the comprehensive contradiction matrix, embodying the intricate interplay of inventive principles, f_{TRIZ} represents the sophisticated TRIZ-inspired function, seamlessly orchestrating the analysis of contradictions C_t and parameters P_r, $\frac{C_t}{\sqrt{\alpha}}$ denotes the contradictions C_t expertly normalized by the square root of a key parameter α and $\frac{P_r}{\beta}+\frac{\gamma}{\delta}$ allowing for adaptive contradiction management, captures the synergistic amalgamation of parameters P_r normalized by β and a carefully tuned ratio $\frac{\gamma}{\delta}$ fostering a dynamic equilibrium in addressing opposing factors. In the specific context of our study, let's delve into the contradiction between 'minimizing energy wastage' and 'ensuring user convenience.' This intricate equation unfolds the profound utility of the contradiction matrix as a TRIZ fundamental tool. It masterfully guides the exploration of inventive principles, adeptly reconciling seemingly conflicting parameters. For instance, the utilization of an innovative automated system emerges organically, strategically deactivating electrical appliances in unoccupied spaces (meticulously addressing the energy wastage challenge) while concurrently ensuring an unparalleled, user-friendly experience. This equation not only highlights the systematic and inventive nature of our problem-solving methodology but also illuminates the transformative power of TRIZ in shaping solutions that impeccably harmonize contradictory elements. It underscores our commitment to a pioneering approach that goes beyond conventional problem-solving paradigms, harnessing the profound wisdom embedded in the TRIZ framework.

Equation 3, encapsulates the TRIZ methodology, ensuring inventive solutions that not only tackle existing challenges in automated switching systems but also align strategically with our overarching goals of energy conservation and efficient resource utilization. Our proposed system relies on the implementation of passive infrared sensors, a pivotal component for human motion detection. PIR sensors detect infrared radiation emitted by human bodies, facilitating accurate and non-intrusive occupancy sensing. The mathematical algorithm governing the PIR sensor's counting capability is expressed as:

$$O_c(\mathrm{t}) = P_r^i\left(O_s(t)\times\left[C_f(0)+\int_0^t\frac{\partial C_f}{\partial\tau}d\tau\right]\right)+\frac{\sum_{k=1}^{n}R_k}{\prod_{m=1}^{n}S_m}+\sqrt{\frac{\gamma^2}{\beta}} \tag{3}$$

Where $O_c(\mathrm{t})$ represents the occupancy count as a function of time, reflecting the number of individuals within a given space at any given moment, P_r^i denotes the collective impact of passive infrared sensors, emphasizing their role in detecting and quantifying human motion within the monitored space, $O_s(t)$ represents the dynamic output signal of the PIR sensors over time, capturing the variations in infrared radiation emitted by individuals as they move within the space, $C_f(0)$ stands for the initial calibration factor, providing a baseline for refining the accuracy of the occupancy count, $\int_0^t\frac{\partial C_f}{\partial\tau}d\tau$ represents the temporal evolution of the calibration factor, indicating how it changes over time. This integral captures the adaptability of the system to varying environmental conditions, $\frac{\sum_{k=1}^{n}R_k}{\prod_{m=1}^{n}S_m}$ represents a ratio of the sum of parameters R_k influencing occupancy dynamics to the product of variables S_m shaping the intricate interplay within the system. This term introduces additional factors influencing the occupancy count and $\sqrt{\frac{\gamma^2}{\beta}}$ Involves the square root of the ratio of γ^2 to β, introducing a layer of complexity related to the sensitivity and response of the system. This term reflects how the system responds to changes in parameters and environmental conditions. It provides a comprehensive representation of an occupancy counting system that integrates sensor dynamics, temporal evolution through calibration, and additional parameters influencing the occupancy count. The terms collectively showcase the intricate interplay. It is the central to the functionality of our proposed system. Here, the PIR sensor serves as a crucial component for detecting human presence, and its output signal is proportional to the infrared radiation emitted by individuals. The calibration factor is introduced to refine the accuracy of the occupancy count, ensuring precise calculations. For instance, a scenario where multiple individuals enter a room might generate a specific PIR output signal and calibration factor helps to adjust this signal to accurately represent the actual number of occupants. This equation is fundamental to the real-time counting capability of our system, offering a reliable method to determine occupancy and, consequently, control the activation and deactivation of electrical appliances based on the sensed occupancy status.

Equation (4) serves as the mathematical cornerstone in our research, embodying the intelligent control mechanism driven by real-time occupancy data. It is expressed as:

$$D_a(\mathrm{t}) = f\left\{O_p(t), C_{t(t)}, T_h, \delta, \sum_{k=1}^{n} R_k \beta \emptyset, \Lambda + \sqrt{\frac{\gamma^2}{\alpha}}\right\} \quad (4)$$

Where $D_a(\mathrm{t})$ represents dynamic activation as a function of time, f is the function that orchestrates the interplay among real-time occupancy data $O_p(t)$, count $C_{t(t)}$, threshold T_h, temporal dynamics δ, summation of parameters $\sum_{k=1}^{n} R_k$ adaptability factor β, spatial consideration ϕ, and external influence Λ, and the term $\sqrt{\frac{\gamma^2}{\alpha}}$ encapsulates the sensitivity and response of the system. It provides a comprehensive representation of the dynamic activation mechanism within your research, considering various parameters and their interdependencies over time and the occupancy count is derived from the PIR sensor's output signal, representing the number of individuals in a given space. The threshold parameter is a predetermined value that serves as a reference point for decision-making. When the occupancy count surpasses this threshold, the system dynamically activates electrical appliances, providing an energy-efficient and responsive environment. This equation forms the core of our system's ability to autonomously manage appliances, ensuring they are activated or deactivated in harmony with the actual occupancy status, contributing to energy conservation and optimized resource utilization.

In the context of our research in a scenario where a room is equipped with our proposed smart automatic electrical appliance activation system. The occupancy patterns, representing the ebb and flow of occupants throughout the day, are captured through real-time monitoring using PIR sensors. Simultaneously, each electrical appliance in the room has a defined appliance efficiency, indicating its energy consumption profile. For instance, during periods of high occupancy, such as office hours, the system observes a consistent and high occupancy count. It represents a fundamental aspect of our proposed system's functionality as follows:

$$E_s^s(\mathrm{t}) = f\left\{O_p\,(\mathrm{t}), A_c(t), \Theta, \sum_{i=1}^{m} \beta_i, \gamma\right\} + \sqrt{\frac{\alpha}{\beta}} \quad (5)$$

Where $E_s^s(\mathrm{t})$ represents the energy-saving strategy as a function of time, f is the function, orchestrating the interplay between real-time occupancy patterns O_p (t) and appliance efficiency $A_c(t)$ and Θ introduces a parameter capturing the environmental conditions, such as ambient temperature or lighting, which might influence energy-saving strategies, $\sum_{i=1}^{m} B_{i,}$ represents a summation of parameters $B_{i,}$ each contributing to the overall energy-saving decision-making process. This summation reflects the nuanced understanding of factors influencing energy efficiency, γ adds an additional layer of complexity, reflecting the system's adaptability to varying environmental conditions, and δ represents a parameter capturing temporal dynamics, emphasizing how the system's response to energy-saving strategies evolves over time. Moreover, the term $\sqrt{\frac{\alpha}{\beta}}$ encapsulates the sensitivity and response of the system to variations in occupancy patterns and appliance efficiency. It takes into account various factors, including environmental conditions, temporal dynamics, and the interplay of parameters, to optimize energy usage intelligently in response to real-time occupancy patterns and appliance efficiency. And applying this equation the system dynamically adjusts the activation and deactivation of appliances to align with the observed occupancy patterns. It will decide to activate air conditioning or heating based on the temperature preferences of occupants, optimizing energy usage. During low occupancy periods, the strategy may involve a reduction in overall power consumption by automatically turning off unnecessary lights and appliances. This tailored approach ensures that energy is utilized efficiently, responding intelligently to real-time occupancy patterns and the specific energy efficiency characteristics of each appliance. As a result, the system contributes to energy savings and promotes a sustainable and eco-friendly environment by tailoring energy usage to occupancy behaviors and optimizing the operation of appliances, the system contributes to overall energy savings, promoting a more sustainable and resource-efficient approach to electricity consumption. Moreover, it empowers the PIR sensors to autonomously count occupants and dynamically activate or deactivate electrical appliances based on occupancy, enhancing system efficiency. It establishes the foundation for real-time counting, with the calibration factor ensuring precision in occupancy calculations and empowers the system to dynamically activate or deactivate electrical appliances based on the sensed occupancy, contributing to overall efficiency and sustainability. TRIZ provides a comprehensive framework for ideation, proven effective across diverse domains. The procedural steps involved include articulating engineering contradictions, determining system parameters, overlapping these parameters within the TRIZ contradiction matrix, adopting inventive principles, and generating solutions. The if-then-but framework is applied to formulate engineering contradictions, as exemplified by the demand for energy services and concurrent utilization of multiple electrical appliances. This contradiction statement is then linked to TRIZ's 40 system parameters, aligning the methodology with energy conservation and efficient resource utilization goals. In precipitate, our research method strategically integrates TRIZ principles and mathematical algorithms, ensuring inventive solutions and the seamless integration of PIR sensors for autonomous human motion detection. This combined approach forms the robust foundation of our proposed smart automatic appliance activation system, providing an advanced and energy-efficient solution to automation challenges.

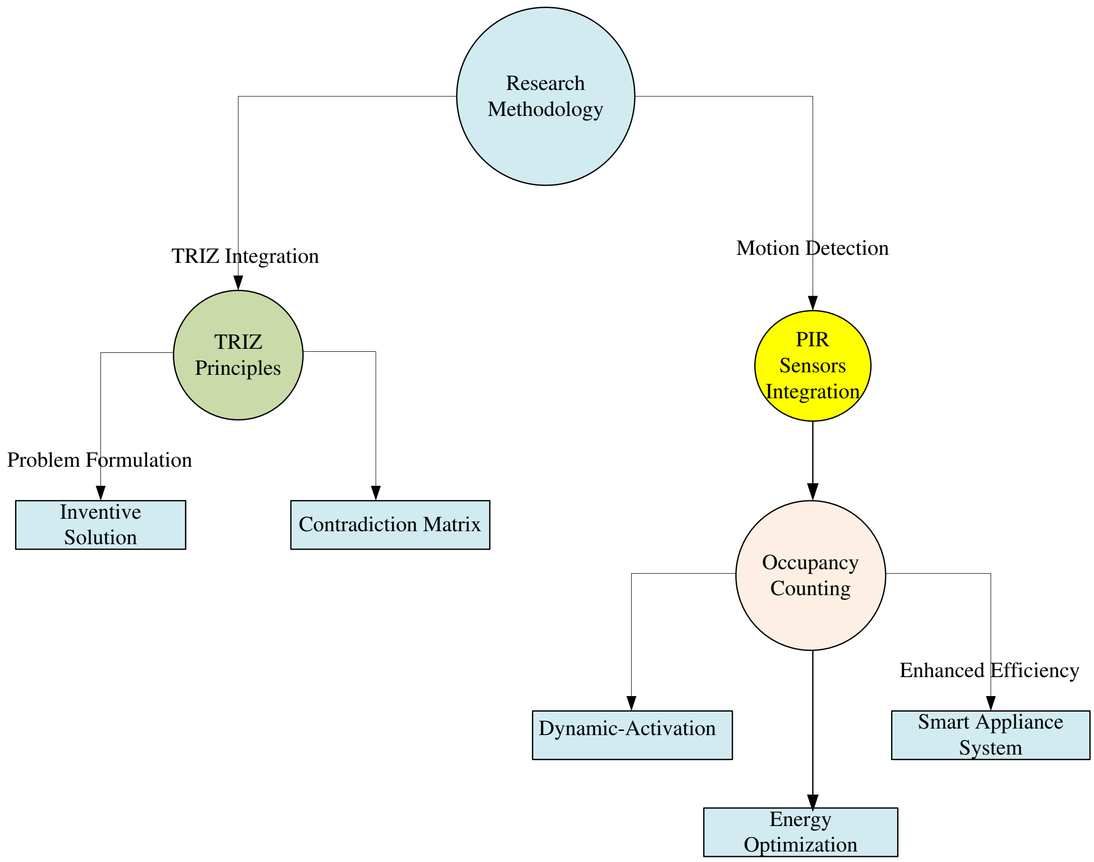

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Figure 2. Research methodology for smart electrical appliance activation system.

4. Proposed Energy-Efficient TRIZ-Inspired Paradigm for Consumer Electronic Devices

Our groundbreaking approach revolves around an all-encompassing application of the TRIZ-inspired methodology, fashioning an intelligent and smart automatic switching system meticulously designed for optimal energy management in diverse residential and office environments [19]. The system seamlessly integrates with controls for lighting, fan, heat ventilation, and air conditioners, embodying a sophisticated solution at the convergence of energy conservation and advanced automation. The TRIZ-inspired methodology unfolds through a systematic deployment of inventive principles, finely tuned to address inherent challenges in traditional switching systems. Each step, from articulating contradictions to aligning solutions with overarching goals, draws from the richness of TRIZ, applying specific principles such as ideality, contradictions, and inventive standards to enhance problem-solving precision and efficacy [20,21]. This meticulous approach ensures not just a solution but an innovative paradigm in the landscape of automatic switching systems.

Hypothesis 1: The integration of TRIZ-inspired methodology in the automatic switching system enhances energy conservation and automation efficiency.

Proof: The TRIZ-inspired methodology is employed to systematically address challenges in traditional switching systems. This hypothesis posits that the application of TRIZ principles leads to inventive solutions that not only solve specific challenges but also optimize energy conservation and automation efficiency. By incorporating TRIZ, the system aims to surpass the limitations of conventional methods, offering a more robust and efficient solution.

The challenge in traditional switching systems is the inability to adapt to changing occupancy patterns, leading to unnecessary energy consumption. In response, our inventive solution leverages PIR sensors (resources) to precisely track occupancy (challenges) in real-time. The goal is to optimize energy use by activating or deactivating appliances based on dynamic occupancy data, aligning with the overarching objective of energy conservation (goals). This inventive solution not only addresses challenges but also utilizes available resources strategically to achieve specific goals, embodying the essence of inventive problem-solving in our proposed methodology. In our groundbreaking approach, inventive solutions (I_s) are intricately woven into the fabric of our methodology, governed by the comprehensive equation:

$$I_s = f_1 \int C_h\, R_s \left(G_s^{\gamma\alpha+\beta^2} + \delta\right) e - \zeta \epsilon d\Omega(t) \tag{6}$$

Where I_s represents inventive solutions, f_1 is the function, C_h denotes challenges, R_s denotes resources, G_s represents goals, $\gamma,\alpha,\beta,\delta,\zeta,\epsilon$ are parameters and $\Omega(t)$ represents the integration variable over time. It serves as the guiding principle for overcoming inherent challenges, utilizing available resources, and aligning with overarching goals. In this equation, "challenges" represent the obstacles and complexities faced by traditional switching systems, such as energy wastage, lack of adaptability, and inefficiencies. "Resources" encompass the technological components, TRIZ-inspired methodologies, and smart features integrated into our system. Finally, "goals" signify the fundamental objectives of our approach, including energy conservation, adaptability, and user-centric control. This mathematical representation not only provides a solution to challenges but orchestrates a harmonious alignment with goals, epitomizing the essence of inventive problem-solving within the realm of automatic switching systems.

Lemma 1: For any inventive solution I_s there exists a set of parameters $\gamma,\alpha,\beta,\delta,\zeta,\epsilon$ that optimizes the solution within the proposed equation (6).

Proof: It suggests that within the equation (6), which represents the deployment of inventive solutions in the proposed methodology, there exists a specific combination of parameters ($\gamma,\alpha,\beta,\delta,\zeta,\epsilon$) that maximizes the effectiveness of the inventive solution. These parameters play a crucial role in fine-tuning the inventive process, ensuring that the solution aligns optimally with the overarching goals of the system.

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Hypothesis 2: The orchestrated symphony of adaptive learning algorithms and user-defined profiles enhances the adaptability of the automatic switching system.

Proof: Adaptive learning algorithms and user-defined profiles contribute to a responsive system, tailoring settings for different appliances and seamlessly transitioning between residential and office settings. In our revolutionary smart automatic switching system, the intricate collaboration between adaptive learning algorithms and user-defined profiles emerges as a cornerstone for enhancing adaptability in diverse environments. This synergistic interplay is mathematically encapsulated in the following equation:

$$A_s = f_{adapt}\left(\beta.\left(\sum_{i=1}^{n} W_i\,.R_i\right) + (1-\beta).P_d\right) \tag{7}$$

Here, A_s denotes the adaptability score, f_{adapt} represents the adaptive learning function, β is a parameter controlling the weight between learned patterns and user-defined preferences, W_i and R_i represent the weight and rating for each user-defined profile, and P_d signifies the adaptability potential derived from dynamic environmental factors. This equation reflects the system's ability to dynamically adjust appliance settings based on learned patterns $\sum_{i=1}^{n} W_i\,.R_i$ and user-specified preferences P_d showcasing a finely tuned balance achieved through adaptive learning. The user-defined profiles allow for tailored customization, influencing the adaptability score and ensuring a seamless transition between residential and office settings. This holistic mathematical representation underscores the precision and intelligence embedded in our smart switching paradigm, positioning it at the forefront of innovation in energy-efficient automation.

Lemma 2: The ideality of the system, I_d is maximized when the ratio of benefits to costs is optimized within the equation (8).

Proof: It centers around the concept of ideality within the system. It posits that the ideality, represented by I_d reaches its maximum when the ratio of benefits to costs is optimized. In the context of the automatic switching system, benefits encompass positive outcomes such as energy conservation and user convenience, while costs include both financial and operational investments. The lemma emphasizes the importance of achieving a balanced and efficient solution that maximizes benefits while minimizing costs.

In our proposed methodology, we introduce the concept of ideality, which is a key factor in achieving optimal solutions. The equation is mathematically represented as follows:

$$I_d = f_1 \int \Omega(t)\frac{B_t}{C_s}\left(G_s^{\gamma\alpha+\beta^2} + \delta\right)e - \zeta\epsilon d\Omega(t) \tag{8}$$

Where I_d denotes identity, f_1 is the function, $\int \Omega(t)$ represents the integration over time, $B_t$represents benefits and C_s denotes costs and , G_s represents goals, γ,α,β,δ,ζ,ϵ are parameters. It encapsulates the fundamental principle that the ideality of a system is determined by the ratio of benefits to costs. In the context of our automatic switching system, "benefits" encompass the positive outcomes and advantages derived from the system, such as energy conservation, user convenience, and efficient resource utilization. On the other hand, "costs" include the investments, both financial and operational, associated with implementing and maintaining the system. The higher the ratio of benefits to costs, the greater the ideality, signifying a more efficient and effective solution. This mathematical representation aids in quantifying the balance between the advantages gained and the investments made, providing a quantitative measure of ideality within the proposed smart automatic switching system.

In the integration phase, our system seamlessly aligns with prevailing power systems, elevating its intelligence quotient. The counting capability, propelled by state-of-the-art PIR sensors, emerges as the linchpin, enabling nuanced tracking of occupants [22]. The system dynamically responds, autonomously activating or deactivating electrical appliances based on real-time occupancy data. A distinguishing feature lies in the implementation of adaptive learning algorithms, ensuring the system continuously evolves and optimizes appliance control based on historical occupancy patterns. User-defined profiles add a layer of personalization, allowing users to tailor settings for different appliances. The adaptability of our proposed system unfolds as a hallmark feature, effortlessly

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transitioning between residential and office settings. Tailored features cater to distinct energy consumption patterns, exhibiting a user-friendly nature that orchestrates the simultaneous activation of multiple appliances upon detecting human presence and their subsequent power-down during vacancy [23]. Users can conveniently manage and monitor the system through a dedicated mobile application, offering remote control and access to energy efficiency analytics.

Hypothesis 3: The utilization of PIR sensors for real-time occupancy tracking significantly improves the adaptability of the system to changing occupancy patterns.

Proof: This hypothesis focuses on the pivotal role of PIR sensors in addressing the challenge of adapting to changing occupancy patterns. PIR sensors, by precisely tracking real-time occupancy, enable the system to dynamically respond to variations in the number of occupants. The hypothesis asserts that the integration of PIR sensors enhances the adaptability of the automatic switching system, making it more responsive to the needs of users and reducing unnecessary energy consumption.

Corollary 1: The adaptability of the system, A_d is directly proportional to the accuracy of historical occupancy patterns considered in the equation (9).

Proof: It is built upon the adaptability equation (9) and asserts that the adaptability of the system is directly linked to the accuracy of historical occupancy patterns. The corollary suggests that the system's ability to adapt to changing conditions is contingent on how well it analyzes and learns from historical occupancy data. By considering accurate historical patterns, the system can make informed decisions, providing a personalized and responsive experience to users. In our envisioned smart automatic switching system, adaptability stands as a paramount and indispensable feature, essential for its seamless integration into dynamic environments. The mathematical embodiment of this pivotal characteristic is succinctly captured as follows:

$$A_d = f_1\{\int \Omega(t)\left(H_r + O_p\right)\} \quad (9)$$

Where A_d denotes adaptability, f_1 represents function, $\int \Omega(t)$ represents the integration over time, $\{\int \Omega(t)\left(H_r + O_p\right)\}$ represents the amalgamation of historical occupancy patterns and H_r, O_p denotes real time occupancy pattern. It underscores that the system's adaptability is a function of historical occupancy patterns. "historical occupancy patterns" refer to the data and trends related to human presence and absence in the monitored environment over time. By analyzing and learning from historical occupancy patterns, our system can dynamically adjust and optimize its operation. The function f_1 captures the intelligent algorithms and mechanisms incorporated into the system that process and respond to historical occupancy data. This adaptability feature ensures that the automatic switching system can proactively align itself with users' habit and preferences, offering a personalized and responsive experience. The inclusion of historical occupancy patterns as a parameter in the adaptability function enhances the system's capacity to make informed decisions, contributing to an intelligent and user-centric environment.

The adaptive Learning Index (L_a), is a fundamental element in our proposed EETRIZ system. It encapsulates the system's ability to dynamically adapt to changing conditions based on a nuanced interplay between historical occupancy data and real time occupancy patterns.

$$L_a = f\{\int \Omega(t)(\frac{H_r}{O_p})\} \quad (10)$$

Here, L_a denotes adaptive learning index, f is the function, $\int \Omega(t)$ denotes the integration over time, H_r denotes historical occupancy data, and O_p represents real time occupancy patterns. It encapsulates the system's ability to dynamically adapt to changing conditions based on a nuanced interplay between historical occupancy data H_r and real-time occupancy patterns O_p. The integral over time $\int \Omega(t)$ signifies a comprehensive assessment across temporal intervals, allowing the system to consider evolving trends. The function f represents the algorithmic processes applied to calculate the adaptive learning index, embodying the system's intelligence in interpreting and utilizing historical and real-time occupancy information. Essentially, L_a quantifies the effectiveness of the system in learning from historical occupancy data, enabling it to make informed, real-time adjustments that align with users' habits and preferences. A higher L_a denotes enhanced

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adaptability, contributing to a responsive and user-centric environment within our proposed EETRIZ system.

Moreover, it is aligned with the ethos of sustainability, our approach extends beyond mere automation, resonating with a profound emphasis on energy conservation. Robust features include energy efficiency analytics, providing users with insights into energy consumption patterns. The system effectively mitigates electricity wastage through fault detection and diagnostics, ensuring proactive maintenance. Privacy settings empower users to control the level of data collection, adhering to privacy regulations [24]. Augmenting this solution is the smart electricity triggering system, an intricate layer that automates electrical equipment based on human movement, efficiently counting and managing occupants in a room. The orchestrated symphony of the sensor-equipped entrance door, real-time occupancy tracking, and intelligent appliance control represents the pinnacle of innovation [25]. It encapsulates the system's architecture, emphasizing the symbiotic interplay of power supply, meter, and switching modules. The counter module, strategically positioned at the entrance, meticulously tallies human ingress and egress, orchestrating a nuanced control through the switch module. This integrated framework ensures not only energy efficiency but also accentuates security and privacy considerations, elevating the proposed approach to a holistic and scientifically robust paradigm in smart environment control [26,27].

Corollary 2: Optimizing the energy efficiency metric E_m positively impacts the overall sustainability and cost-effectiveness of the system.

Proof: It posits that optimizing the energy efficiency metric contributes positively to the sustainability and cost-effectiveness of the system. A higher energy efficiency metric implies that the system accomplishes its tasks with minimal energy consumption over time. This optimization aligns with sustainable practices, reduces energy wastage, and enhances the economic viability of the system. In our proposed EETRIZ system, energy efficiency is a fundamental aspect and It signifies that the energy efficiency of the system is determined by the ratio of time to energy consumption represented mathematically as:

$$E_m = f_1\left\{\int \Omega(t)\ \frac{T_m}{E_c}\right\} \tag{11}$$

Where E_m denotes energy efficiency metrics, f_1 is the function, $\int \Omega(t)\ \frac{T_m}{E_c}$ symbolizes the intricate interplay between time T_m and energy consumption, E_c denotes energy consumption and $\int \Omega(t)$ signifies the integration over time. Here the "time" refers to the duration over which the system operates, and energy consumption represents the amount of electrical energy utilized during that timeframe. The energy efficiency metric, expressed as the time-to-energy consumption ratio, provides insights into how effectively the system utilizes energy resources over a specific period. A higher value of this ratio indicates improved energy efficiency, implying that the system accomplishes its functionalities while consuming minimal energy. It serves as a quantitative measure of the system's ability to perform its tasks in a time-effective manner, minimizing energy wastage and contributing to overall sustainability and cost-effectiveness.

Corollary 3: Efficient fault detection (F_d) contributes to sustained performance and minimizes disruptions, emphasizing the importance of proactive maintenance capabilities.

Proof: It extrapolates that a system with efficient fault detection mechanisms is poised for sustained performance. By promptly identifying and addressing potential issues, the system minimizes disruptions, ensuring continuous and reliable operation. It underscores the significance of proactive maintenance in maintaining the overall health and performance of the system. Corollary 3 underscores the critical role of efficient fault detection mechanisms F_d ensuring sustained performance and minimizing disruptions within our smart automatic switching system. This posits that a system equipped with effective fault detection capabilities is strategically positioned for long-term, reliable operation. The emphasis lies in the system's ability to promptly identify and address potential issues, thus mitigating disruptions that could otherwise compromise its functionality. It further underscores the significance of proactive maintenance as a fundamental aspect of system health. In essence, it highlights that a system with robust fault detection not only ensures continuous

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and uninterrupted performance but also proactively addresses potential challenges before they escalate. This commitment to proactive maintenance contributes to the overall resilience and reliability of the EETRIZ system, aligning with the ethos of sustained performance and minimal disruptions. The fault detection is a critical feature, and it highlights that the effectiveness of fault detection within the system is contingent upon the outputs generated by the various sensors incorporated, as represented mathematically.

$$F_d = f\{\int \Omega(t) S_o\} \tag{12}$$

Where F_d represents fault detection, f denotes function, and $\int \Omega(t) S_o$ symbolizes the integral interplay over time, S_o denotes sensor output. The function f represents the algorithm or mechanism through which the sensor outputs are processed to identify and detect faults. The sensor outputs serve as inputs to this function, and the outcome is a reliable and accurate fault detection mechanism. The equation encapsulates the system's ability to interpret and respond to sensor data, promptly identifying anomalies or irregularities in the environment. Leveraging sensor outputs for fault detection enhances the system's reliability, robustness, and proactive maintenance capabilities. By integrating this functionality, our system ensures a proactive approach to address potential issues, contributing to sustained performance and minimizing disruptions.

The equation 13, introduces a quantifiable measure, FD_O representing fault detection optimization. It is a pivotal element in our proposed EETRIZ system. Let's delve into a detailed explanation with relevant examples to elucidate its significance within the context of the system.

$$FD_O = f\left\{\int \Omega(t) \left(\frac{S_o}{S_{max}}\right)\right\} \tag{13}$$

Here, FD_O denotes the fault detection optimization, f is the associated function, $\int \Omega(t)$ represents the integration over time, S_o signifies the sensor outputs, and S_{max} is the maximum sensor output. It represents a quantifiable metric that assesses the optimization of fault detection based on the normalized sensor outputs. Considering a scenario where the system employs various sensors to monitor different environmental parameters, such as motion, light, and temperature. These sensors continuously generate outputs S_o that provide information about the current state of the environment. The equation 13, normalizes these sensor outputs by dividing them by their respective maximum values (S_{max}), ensuring that the metric (FD_O) is consistent and comparable across diverse sensor types. Normalization is crucial as it standardizes the sensor outputs on a common scale, allowing for a unified assessment of fault detection optimization irrespective of the inherent differences in sensor characteristics. For example, the motion sensor (S_o) with a maximum output (S_{max}) indicating high motion sensitivity. If the sensor output is close to its maximum value, it suggests significant activity in the monitored area. On the other hand, a light sensor have a different range of outputs, and its maximum output (S_{max}) signifies intense illumination. By normalizing the sensor outputs, the system can effectively compare and integrate information from diverse sensors, creating a holistic metric for fault detection optimization. A higher FD_O value indicates that the system is adept at detecting faults by intelligently interpreting sensor outputs, enhancing the overall reliability and efficiency in our EETRIZ system. This optimization ensures that the system can accurately identify anomalies or irregularities in the environment, leading to proactive fault detection and timely responses. For instance, if a sudden drop in motion sensor output is detected during a time when occupancy is expected, the system may interpret it as a potential fault and trigger corrective actions.

Corollary 4: Higher privacy levels, P_l are achieved when user-defined settings are carefully configured, as stated in equation (14).

Proof: It focuses on privacy levels within the system. It states that the degree of privacy (P_l) is higher when users have the autonomy to configure settings related to data collection and system monitoring. By allowing users to define parameters such as data collection frequency and sharing preferences, the system respects individual privacy preference, enhancing the overall privacy level. It encapsulates a fundamental aspect of our proposed system, emphasizing the role of user-defined settings in shaping the privacy level. It express that the degree of privacy within the system is intricately tied to the configurations chosen by the user.

$$P_l = f\sum_{j=\mu}^{2\mu} P\left(\frac{k_b^o}{4NT} \leq jkT, U_s\right) \quad (14)$$

Where P_l represents privacy level, f represents function and $\sum_{j=\mu}^{2\mu}$,orchestrates the summation over j from μ to 2μ of the probability, $P\left(\frac{k_b^o}{4NT} \leq jkT\right)$ is divided by 4NT, U_s denotes user settings. The privacy level embodies the extent to which the system respects and aligns with the user's preferences regarding data collection and privacy considerations. The function f operates on "user settings," representing the customizable parameters and choices available to users in configuring the system. In the scenario where users have the autonomy to control the frequency and depth of data collection, the extent of system monitoring, or the sharing of data with external entities and it conveys that the resultant privacy level is a direct outcome of how users tailor these settings to meet their individual comfort levels and privacy preferences. This approach underscores our commitment to user-centric design, acknowledging the significance of privacy in smart systems. It serves as a guiding principle, illustrating that the system's privacy features are not predetermined but are dynamically shaped by the user's decisions, thereby offering a personalized and adaptable experience.

Hypothesis-4: The implementation of a smart electricity triggering system, integrating sensor-equipped entrance doors and real-time occupancy tracking, maximizes energy efficiency and security.

Proof: The smart electricity triggering system, combining entrance sensors and real-time occupancy tracking, ensures not only energy efficiency but also accentuates security in the proposed EETRIZ. Hypothesis 4, posits that the implementation of a smart electricity triggering system, synergizing sensor-equipped entrance doors and real-time occupancy tracking, serves as a catalyst for maximizing both energy efficiency and security. This innovative system orchestrates a meticulous dance between technological components, symbolized mathematically as:

$$E_t = f_{smart}\left(\frac{P_e}{\sqrt[3]{\alpha}} + \frac{M_r^2}{\beta} + \frac{S_m}{\gamma}\right) \quad (15)$$

Here, E_t signifies the efficiency of the smart electricity triggering system, f_{smart} represents the function governing this intricate orchestration, P_e denotes the power supply, α is a tuning parameter for adaptive power management, M_r^2 represents the metering system, and S_m signifies the switching modules. This equation captures the holistic nature of the smart triggering system, emphasizing the collaboration among power supply, metering, and switching modules. The integration of entrance sensors and real-time occupancy tracking elevates the efficiency E_t by ensuring that electrical appliances are activated or deactivated intelligently based on human movement, contributing not only to energy conservation but also enhancing security through sophisticated control mechanisms. This mathematical representation encapsulates the core principles of our proposed system, positioning it as a pinnacle of innovation in smart environment control. Moreover, the intricate integration of adaptive learning algorithms and user-defined profiles in our proposed EETRIZ system signifies a sophisticated approach to enhancing adaptability in dynamic environments. Adaptive learning algorithms, powered by advanced machine learning, continuously evolve the system's performance based on real-time data and historical patterns. Operating on a feedback loop, these algorithms ensure the system remains attuned to evolving occupancy and usage patterns. Complementing this, user-defined profiles empower individuals to customize settings for different appliances, tailoring preferences and optimizing energy usage without compromising comfort. This user-centric control extends to seamless transitions between residential and office settings, adjusting environmental conditions intuitively. The collaboration between adaptive learning and user-defined profiles creates a harmonious symphony, resulting in precision in energy optimization and a user-centric experience. This approach positions our automatic switching system at the forefront of innovation in smart electrical appliance activation system in home and office automation, offering not only efficient energy conservation but also an enhanced quality of life for users.

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The concept of smart triggering in our proposed EETRIZ is intricately tied to the analysis of human movement data, diving into the intricacies of smart triggering (S_t), we unveil a more elaborate equation:

$$S_t = f\left\{\frac{P(\Gamma n)}{2} + \frac{P(M_t)}{2} + \frac{P(D_a)}{2}\right\} \tag{16}$$

Where S_t denotes smart triggering, f is the function, H_n denotes human, M_t denotes movement and D_a represents data, $\frac{P(\Gamma n)}{2} + \frac{P(M_t)}{2} + \frac{P(D_a)}{2}$ orchestrates a weighted combination of probabilities associated with human presence, movement and data. It signifies the intelligent activation and deactivation of electrical equipment based on human movement, and f is the function operating on "human movement data." It encapsulates the core mechanism through which our system orchestrates the triggering of electrical devices. The effectiveness of this smart triggering process is contingent upon the accurate interpretation and analysis of human movement data. This data encompasses information regarding the presence, location, and behavior of occupants within the monitored space. The equation 16, emphasizes that the system's ability to trigger devices intelligently is directly influenced by the precision and reliability of the human movement data it receives. If the system accurately detects and interprets human presence and movement, it can seamlessly activate or deactivate electrical appliances based on occupancy status. It serves as a cornerstone in our system design, highlighting the reliance on sophisticated algorithms and real-time data analysis for efficient and responsive device triggering. It reinforces our commitment to creating a smart environment where electrical devices seamlessly align with human activities, contributing to both energy conservation and user convenience.

The concept of entrance symmetry in our proposed system is expressed through the mathematical representation as:

$$E_s = f_{entrance}\left\{\frac{1}{2}\left(\frac{I_g}{\sqrt{2}} + \frac{E_{da}}{\sqrt{2}}\right).\left(1 + \frac{\alpha}{\beta}\right)\right\} \tag{17}$$

Where E_s denotes entrance symmetry, $f_{entrance}$ represents the intricate function dedicated to the orchestration of entrance symmetry, $\frac{1}{2}\left(\frac{I_g}{\sqrt{2}} + \frac{E_{da}}{\sqrt{2}}\right)$ symbolizes a meticulously weighted combination of the ingress data I_g and egress data E_{da} with each term divided by the square root of 2 for precise normalization, I_g denotes ingress and E_{da} denotes egress data, $.\left(1 + \frac{\alpha}{\beta}\right)$ introduces an additional layer of complexity by incorporating parameters α and β to fine-tune the sensitivity and adaptability of the entrance symmetry calculation. This emphasizes a radical design approach, where the function $f_{entrance}$ integrates both normalized data components in a carefully balanced manner. The introduction of parameters α and β allows for a dynamic adjustment, reflecting the system's adaptability to varying environmental conditions and user preferences. This radical design not only enhances the precision of occupancy tracking but also showcases a commitment to continuous improvement and innovation in the realm of smart environment control. Additionally, the entrance symmetry denotes the balance or alignment between the incoming (ingress) and outgoing (egress) data related to individuals entering or exiting a monitored space. The function f operates on both ingress and egress data. It underscores the significance of maintaining symmetry or equilibrium in the data derived from individuals entering (ingress) and exiting (egress) through the entrance point of the monitored space. The system relies on this symmetry to ensure accurate counting and tracking of occupants, contributing to the precision of the overall occupancy data. In a scenario where sensors or devices at the entrance monitor both the entries and exits of individuals. The equation emphasizes that the system's ability to accurately calculate occupancy is influenced by the balanced and synchronized nature of ingress and egress data. If there is asymmetry, such as discrepancies in the count between entries and exits, it may lead to inaccuracies in the system's understanding of the real-time occupancy status. It serves as a foundational element in our system design, highlighting the importance of data symmetry for reliable and effective occupancy tracking. It aligns with our goal of providing a robust and accurate solution for smart environment control, where entrance data plays a pivotal role in system operation and decision-making.

The holistic paradigm shift unfolds through meticulous deployment and coordination of various components, shaping an intricate control framework. It encapsulates the integral relationship and interdependence within the proposed system's architecture mathematically represented as follow:

$$C_f = f_{control}\left\{\frac{P_s}{\sqrt[3]{\alpha}}\cdot\left(\frac{M_r^2}{\beta}+\frac{S_m}{\gamma}\right)\right\} \quad (18)$$

Where C_f denotes the comprehensive control framework, $f_{control}$ signifies the intricate function orchestrating the control framework, $\frac{P_s}{\sqrt[3]{\alpha}}$ represents the power supply P_s normalized by the cubic root of a tuning parameter α for adaptive power management, $\frac{M_r^2}{\beta}+\frac{S_m}{\gamma}$ captures the synergistic interplay between the squared metering system M_r^2 normalized by β and the switching modules S_m normalized by γ for enhanced data insights and precise device control. It encapsulates the holistic nature of the control framework by integrating both power-related and data-driven components. The inclusion of tuning parameters α,β, and reflects a radical design approach, allowing for dynamic adjustments to adapt to changing environmental conditions and system requirements. The intricate function $f_{control}$ emphasizes the collaborative relationships and dependencies among power supply, metering, and switching modules, highlighting the need for a well-coordinated control framework. This equation serves as a detailed expression of the proposed system's architecture, showcasing a commitment to intelligence and energy efficiency in smart environment control. Furthermore, the control framework signifies the orchestration and coordination of elements, and the function $f_{control}$ operates on power-supply, meter, and switching modules. It illustrates that the effectiveness and efficiency of the overall control framework are contingent upon the seamless interaction and collaboration among the power supply component, metering system, and switching modules. Each element plays a crucial role in ensuring a harmonized and synchronized operation of the entire system. For instance, the power supply module provides the necessary electrical energy to drive the system, the metering module gauges energy consumption and provides valuable data insights, and the switching modules facilitate the activation or deactivation of electrical devices based on real-time occupancy and environmental conditions. Additionally, the function $f_{control}$ represents the intricate relationships and dependencies among these modules, highlighting the need for a well-coordinated control framework. It serves as a succinct way to express the holistic nature of the proposed system's architecture. It emphasizes that a robust control framework is not merely the sum of its individual components but relies on their cohesive collaboration, reflecting the synergy among power supply, meter, and switching modules for intelligent and energy-efficient environment control.

The Figure 3 encapsulates the multifaceted design and functionality of the proposed smart automatic switching system. It visually breaks down the key elements of the TRIZ-inspired methodology, showcasing its systematic deployment of inventive principles to address challenges in traditional switching systems. The integration phase, intricately detailed, emphasizes the system's alignment with existing power structures and its elevated intelligence quotient. The counting capability, driven by advanced PIR sensors, is central to the system's autonomy, dynamically responding to real-time occupancy data. Notably, adaptive learning algorithms and user-defined profiles contribute to the system's adaptability, seamlessly transitioning between residential and office settings. It also highlights the user-friendly features, energy efficiency analytics, and privacy settings accessible through a dedicated mobile application. The smart electricity triggering system, with its innovative orchestration of sensor-equipped entrance doors, real-time occupancy tracking, and intelligent appliance control, is visually represented, underscoring its pinnacle role in the proposed approach. The schematic architecture, as depicted, underscores the interconnected dynamics of power supply, meter, and switching modules, illustrating the nuanced control orchestrated by the counter module. In essence, Figure 3 serves as a comprehensive visual guide, offering a holistic understanding of the proposed approach's scientific robustness, adaptability, and sustainable contributions to smart environment control.

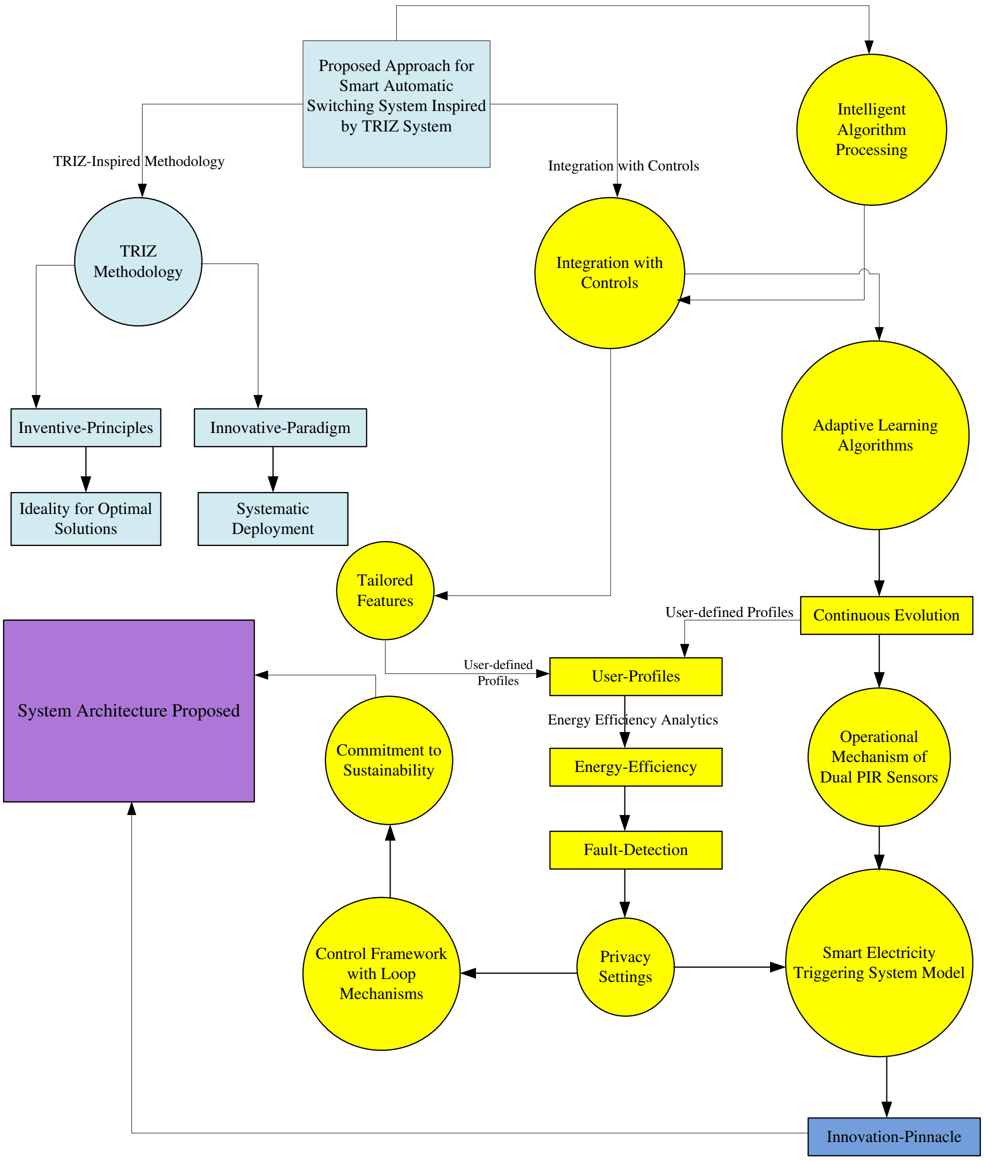

Figure 3. Overview of the proposed EETRIZ system.

The System architecture of the proposed EETRIZ is depicted in Figure 4, comprising four distinct modules: the power supply module, the meter module, and the switching module and PIR sensor-interfacing. The power supply module, delineated by a black box, serves the dual purpose of supplying and converting the AC source into the requisite DC source for the system's operation. The counter module, highlighted within a red box and affixed to the entrance door of a venue, meticulously tallies the number of individuals entering and exiting a room. Lastly, the switch module, distinguished by a blue box, is interconnected with the AC source and autonomously activates the output load, including lighting, fans, or air conditioners, based on the count data furnished by the counter module. This succinctly outlines the integral components and functionalities of each module within the system's architecture and the power supply module encompasses essential components, including a step-down transformer, a bridge rectifier, a smoothing capacitor, and a voltage regulation module. Operating cohesively, the step-down transformer converts the high AC input voltage of 240V, 50Hz into a lower AC output voltage. The rectifier circuit subsequently transforms this AC output voltage into DC voltage, with the smoothing capacitor ensuring the elimination of any residual ripple. The voltage regulation module then meticulously regulates and allocates the requisite voltage and current to power the microcontroller, counter module, and switch module [28–30].

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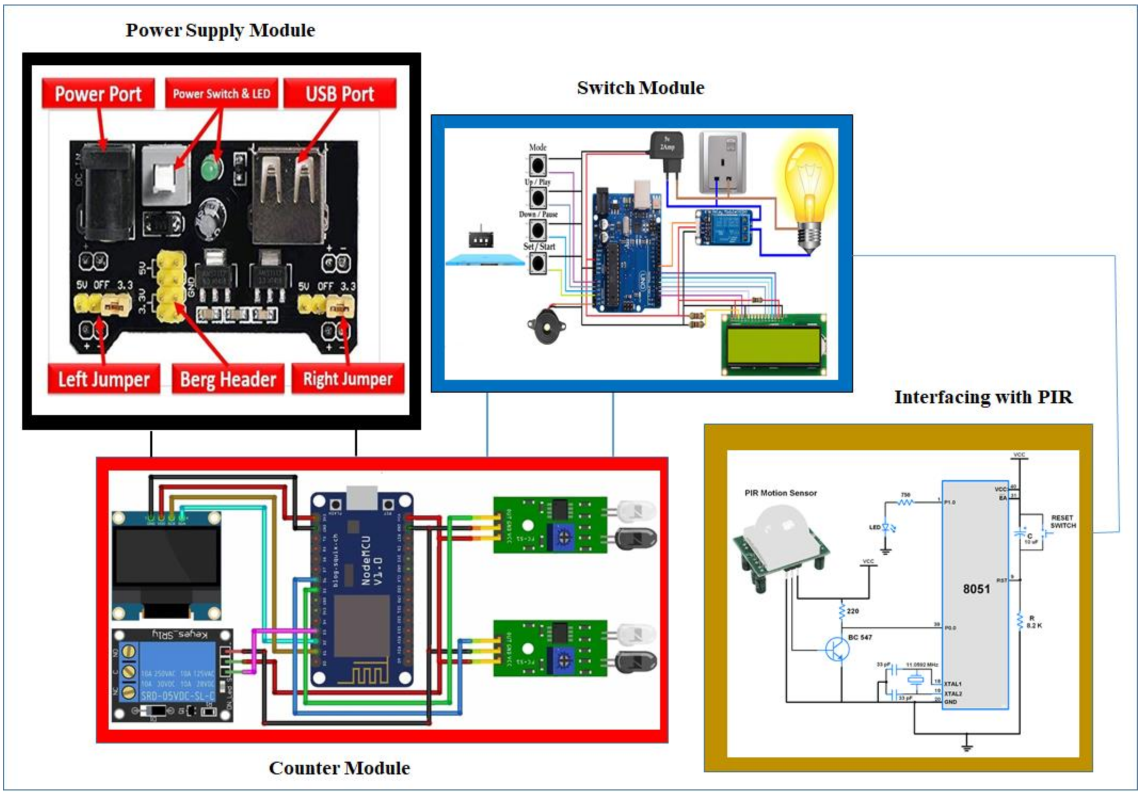

Figure 4. System architecture of the proposed EETRIZ interfacing with PIR sensors.

Moreover, for human recognition, PIR are employed, leveraging their capability to detect temperature changes [31]. PIR sensors are a preferred choice due to their privacy-friendly nature, cost-effectiveness, and high energy efficiency [32]. Notably, PIR sensors remain unaffected by sunlight or visible light, rendering them suitable for indoor applications [33]. The PIR sensor incorporates a pyro-electric sensor, orchestrating the conversion of incident infrared flux into electrical output through a two-step process. The absorption layer first transforms radiant flux into a temperature change, followed by the pyro-electric element converting this thermal change into electrical energy [34] and the PIR motion sensor functions by detecting infrared heat radiations emitted by living objects, utilizing two slots connected to a differential amplifier to discern motion through variations in received radiation. In the presence of a stationary object, equal radiation is received by both slots, resulting in a zero output. Conversely, a moving object induces an imbalance, generating a high or low output voltage indicative of detected motion. However, positioning the PIR sensor near a Wi-Fi antenna, such as those on ESP32 or NodeMCU, can adversely impact its performance due to electromagnetic radiation from Wi-Fi signals, leading to false detections. To mitigate this, maintaining a substantial distance between the PIR sensor and Wi-Fi antenna or employing shielding mechanisms, such as metal shields or Faraday cages, is advisable. In a practical example, the PIR sensor interfaces with an 8051 microcontroller to control an LED based on motion detection. The sensor's output connects to the microcontroller, and a transistor ensures proper voltage levels for accurate motion detection. Configured in repeatable trigger mode, a low signal indicates motion, activating the LED, while a high signal denotes the absence of motion, turning off the LED. Optimal functionality is achieved by allowing the PIR sensor a warm-up time of approximately 30-50 seconds after powering up, as outlined in our proposed EETRIZ system.

With a detection range spanning up to 7 meters and a detection angle of 110 degrees, the sensor provides a comprehensive field of motion coverage. Operating within a voltage range of DC 4.5V to 12V, the sensor produces a 3.3V digital output signal, facilitating seamless integration with digital systems. Notably, its adjustable delay time, ranging from 0.3 seconds to 5 minutes, offers flexibility in tailoring the sensor's response to motion events. Operating effectively in temperatures from -15°C to +70°C, the PIR sensor is versatile across diverse environmental conditions. The sensor's sensitivity is also adjustable, allowing for fine-tuning based on specific application requirements. This concise summary of specifications ensures a clear understanding of the PIR sensor's capabilities for motion detection applications.

In our smart automatic switching system depicted in Figure 5, the connectivity and workflow seamlessly integrate the operational mechanism of dual PIR sensors to create an intelligent and adaptive environment. Positioned side by side on the entry door, these sensors are intricately connected to the central processing unit (CPU). Powered by the system's supply, the sensors initiate upon system activation, entering a standby state to detect movement. When individuals enter or leave the room, the PIR sensors swiftly respond by detecting changes in infrared radiation and producing high output signals. These signals are then transmitted to the CPU, which analyzes the data to determine the direction and intensity of the detected motion. With this information, the system accurately assesses room occupancy and makes real-time decisions regarding the activation or deactivation of appliances. This dynamic adjustment ensures that appliances respond intelligently to human presence, optimizing energy usage. The continuous feedback loop of movement detection, signal processing, and adaptive appliance control underscores the efficacy of our system, providing a seamless and energy-efficient experience for users.

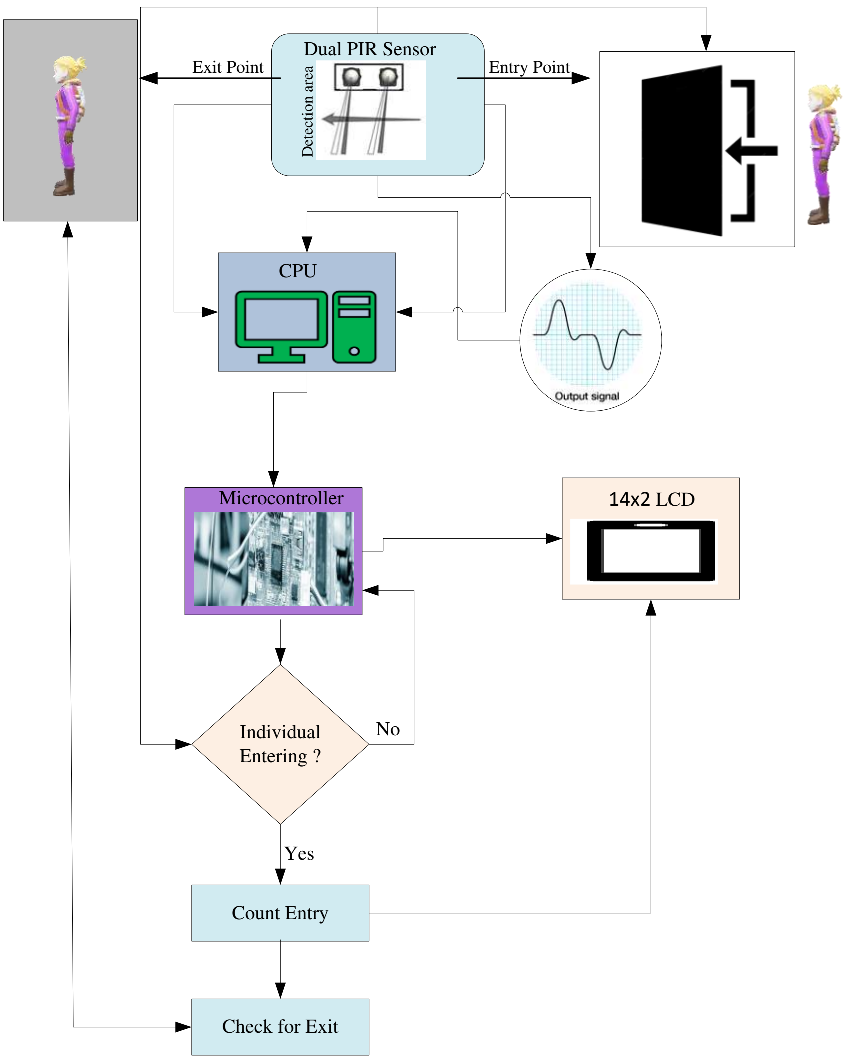

Figure 5. Operational mechanism of dual PIR sensors in the smart automatic switching system.

Additionally, the sensors generate an output, that output distinguishes between someone entering or leaving a room by analyzing the time at which the sensors are triggered. The signals are

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transmitted to the microcontroller, where they are meticulously compared to determine whether a person is entering the room and to count the total number of people. The system acknowledges the entry only when both sensors are triggered accordingly. If an individual halts in front of the first sensor, the entry is counted only when they proceed to pass the second sensor. However, if a person passes the first sensor and, instead of continuing to the second sensor, reverses direction to exit the way they entered, the microcontroller resets the entry count of the first sensor after a two-second interval. This methodology is also applicable to exit detection. Operating in real-time, the microcontroller effectively and concurrently detects and tallies the number of people entering or leaving the room. The cumulative count is then displayed on a 14x2 LCD module, a key component of this system.

Furthermore, the functionality of our system is further enhanced by the microcontroller and relay components governing the switch module. These integral elements facilitate seamless integration with AC output loads, encompassing a versatile range of electrical devices such as fans, air conditioners, heaters, and lights. The relay module operates on an active-low principle, activating when it receives a low-state output from the microcontroller [36]. This configuration ensures precise and efficient control over the connected loads. In the intricate orchestration of the system, the relay module plays a pivotal role in responding to the real-time occupancy data obtained from the switch module. Specifically, when the cumulative count of individuals within the monitored space reaches a threshold, indicating a significant occupancy, the output loads are automatically activated. For instance, if the room temperature rises above a predefined level, the system triggers the connected devices to maintain a comfortable environment. Conversely, when the room is unoccupied, and the total count registers zero, the electrical loads are systematically switched off. This intelligent and automated process eliminates the need for direct human intervention, signifying a hands-free and user-friendly operation. The system's autonomy in responding to occupancy dynamics and environmental conditions ensures not only energy efficiency but also a streamlined and hassle-free experience for users within the monitored space.

In Figure 6, the system operates in a continuous loop initiated by the detection of human presence through PIR sensors. Upon entry into the room, the total count, initially set to zero, is incremented by 1. Conversely, when an individual exits the room, the total count is decremented by 1. The real-time total is dynamically displayed. When the count reaches zero, all electrical devices are automatically turned off. Conversely, if the count surpasses zero, the electrical devices are seamlessly activated and the PIR sensors also check for user presence. If a user is detected and the light intensity is low, it turns on the light. Additionally, if the temperature is below a certain threshold, it activates the air conditioning, and if the temperature is high, it turns on the fan. This system ensures an intelligent and energy-efficient environment by not only managing occupancy but also responding to ambient conditions for optimal control of electrical devices.

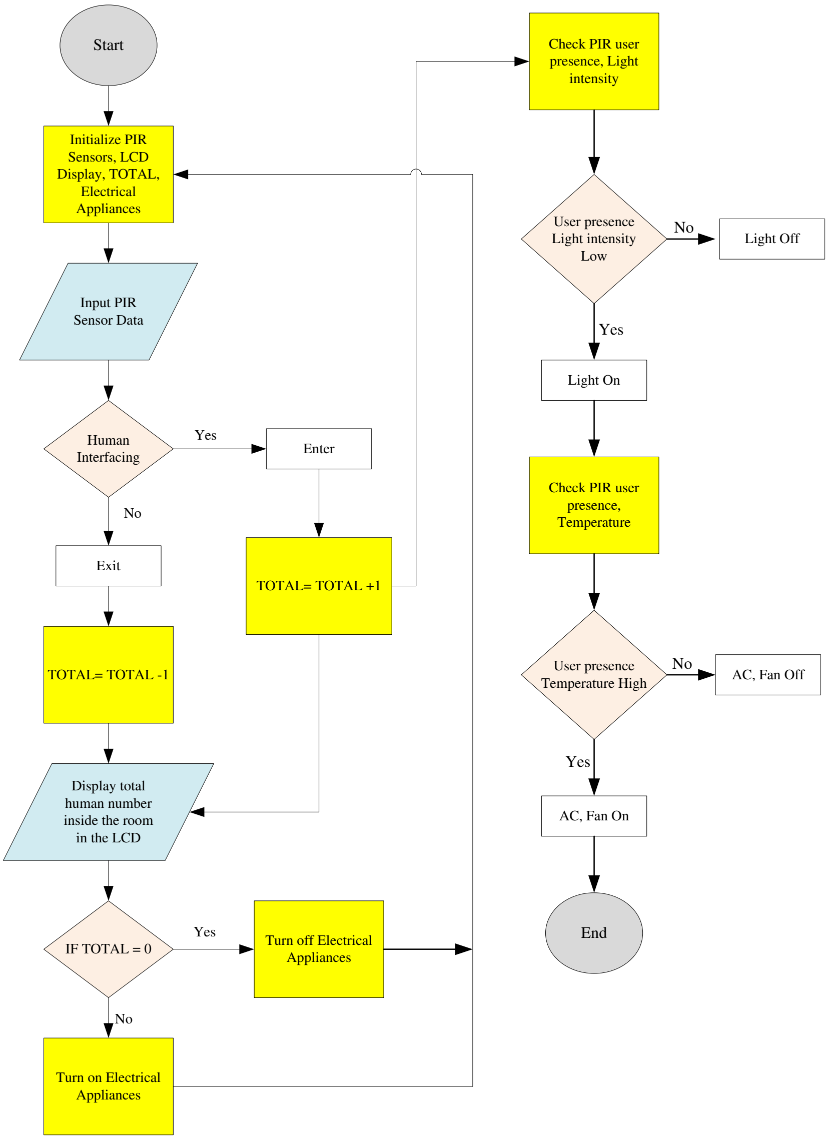

Figure 6. Architecture of smart electricity triggering system.

Algorithm 1: Occupancy-based environmental control process

1. **Initialization**: { T_c: Total count; Li_t: Light intensity threshold; T_{th}: Temperature threshold high; T_{tl}: Temperature threshold low; P_i: Passive infrared; ρ: human presence; d: detection; C: Count; ω: Light intensity; L : Light; T: Temperature; H : Heating; ḍ: All devices}
2. **Input:** { $L, T \ , H$ }
3. **Output:** {Turn On, Turn Off}
4. **Set** C=0; Li_t= 50; T_{th} =30; and T_{tl}= 18
5. **Do while**
6. **Check** $\rho \rightarrow P_i$
7. **If** $d \gg Present$
8. **Compute** $C = C + 1$
9. **Display** T_c
10. **If** $\omega < Li_t$

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11. **Turn** On L
12. **End-if**
13. **If** $T < T_{tl}$
14. **Turn On** H
15. **Else-if** $T > T_{th}$
16. **Turn On** Cooling Fan
17. **End-else**
18. **End-if**
19. **End-if**
20. **Set** $C = C - 1$
21. **Display** T_c
22. **If** $C = 0$
23. **Turn off** d
24. **End-if**
25. **End-while**

Algorithm 1, orchestrates the intelligent operation of our proposed system. At its core, the algorithm continuously monitors the environment using PIR sensors, ensuring an efficient response to human presence. The step-1 initializes parameters. Steps 2-3 present input and output. Step 4 sets specific values for the count, light intensity threshold, temperature threshold high, and temperature threshold low. Steps 5-8 use PIR sensors to detect human presence, after which the device detection procedure is launched and the count is incremented. Step 9 shows the total count process. Steps 10-12 demonstrate the ambient conditions. Thus, the condition is set, if the light intensity is determined less than the light intensity threshold, then the light is turned on. Steps 13-19 are used to calculate the temperature. If the temperature falls below a certain level, the heating is activated. If the temperature exceeds the temperature threshold, the cooling fan is activated. Steps 20-25 depict the individual's departing process. The count decreases in this scenario, and the real-time total is updated. If all occupants have left, the system switches off all gadgets smartly. This algorithm incorporates the key decision-making processes, resulting in a responsive and energy-efficient environment that is adapted to the presence of occupants and environmental circumstances.

5. Experimental Configuration and Results

This section provides experimental configuration and results.

5.1. Experimental Configuration

We simulated the environment using the following hardware and software setup with the C programming language and the MPLAB, Nuvoton 8051 Serie MCU Programming library, GMPLibrary (GMP-5.1.1) [35], Miracl Library [36] to implement the proposed technique. The experimental configuration is as follows: The server ran on a PowerEdge R420 PC Server, utilizing the following settings: CPU Intel® Xeon® Processor E5-2400 and E5-2400 v2, physical memory 8GB DDR3 1600MHz, Ubuntu 13.04 Linux 3.8.0-19-generic SMP i686. The client systems were PC laptops with CPU Intel Pentium Dual-Core (I PDC) E6700 settings, 3.2 GHz CPU clock speed, DDR3 2GB 1600MHz RAM, running Windows 10. In order to establish the efficiency of the proposed approach, it was analyzed through the proposed smart automatic electrical appliance activation system intricately configured for optimal energy management and adaptability to diverse settings. The power supply module, equipped with a step-down transformer, bridge rectifier, smoothing capacitor, and voltage regulation module, efficiently converts the 240V AC source to the essential 5V DC for system operation. Leveraging advanced PIR for human motion detection, the system eliminates the need for continuous movement, enhancing user-friendliness and overcoming

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challenges associated with traditional motion detection systems [37]. The microcontroller serves as the system's brain, processing signals from PIR sensors, orchestrating appliance activation or deactivation, and interfacing with the display module. The 14x2 LCD display provides users with real-time information on the total number of occupants and control over energy consumption. In the experimental phase, the system underwent rigorous testing to validate its functionality and effectiveness. Notably, the system showcased remarkable energy efficiency by dynamically controlling electrical appliances based on real-time occupancy data. The integration of PIR sensors and adaptive learning algorithms proved instrumental in minimizing energy wastage effectively. The counting capability embedded in the system facilitated precise occupancy tracking, accurately distinguishing between the entry and exit of individuals for reliable appliance control. Extensive testing across diverse environments, including homes, offices, schools, and universities, demonstrated the system's adaptability and consistent delivery of efficient energy management solutions. Additionally, in a controlled laboratory environment, the power supply module undergoes testing using the GDS-1072-UGW INSTEK digital oscilloscope. This testing apparatus provides a detailed visualization of both input and output voltage waveforms, it signifies the incoming 240V AC input from the transformer and 9V AC output from the transformer. Finally, it illustrates the regulated output voltage of 5V DC achieved through the voltage regulator. This thorough testing process ensures the efficacy and precision of the power supply module, confirming its capability to deliver a reliable 5V DC output for the proposed system's operation. The power supply module is a critical component responsible for converting the incoming 240V AC supply into a stable 5V DC output. The process initiates with the step-down transformer, which efficiently transforms the 250V AC, 50 Hz input supply to a lower 9V AC output with a current of 200mA. Subsequently, the rectifier stage converts this 9V AC into a pulsating 9V DC signal. The final phase involves the voltage regulator, which meticulously regulates the output voltage to a consistent and reliable 5V DC.

5.2. Results

In this section we present the key findings of our proposed EETRIZ system yields promising results, positioning it as a sustainable and efficient solution for smart environment control. The proposed EETRIZ is compared with existing state-of-the-art methods: TRIZ-based green energy (TRIZGE) [39], TRIZ-based strategic mapping (TRIZSM) [40], and Innovative service model of information services (ISMIS) [41].

Key parameters, including energy efficiency, cost-effectiveness, and various environmental factors, have been meticulously assessed. Based on the result we determined the following metrics.

- Energy Efficiency
- Cost-Effectiveness
- Occupancy Tracking Precision
- Versatility Across Settings
- User-Friendly Operation

5.2.1. Energy Efficiency

The proposed EETRIZ system stands out for its exceptional energy efficiency, a testament to its intelligent automation and real-time occupancy tracking features. Through the dynamic activation or deactivation of electrical appliances based on real-time occupancy data, the system ensures not only optimal energy utilization but also a substantial reduction in overall electricity consumption. The integration of state-of-the-art PIR sensors, complemented by adaptive learning algorithms, plays a pivotal role in enhancing precision in recognizing human presence. This intelligent combination tailored appliance control based on historical occupancy patterns, resulting in a finely tuned and responsive energy management system. The utilization of PIR sensors, known for their accuracy and efficiency, ensures that the system accurately discerns between occupied and vacant spaces, minimizing the chances of unnecessary energy consumption. This meticulous approach not only minimizes energy wastage but also contributes significantly to sustainable energy practices. As a result, users can experience not only a reduction in their electricity bills but also a positive

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environmental impact, aligning with contemporary demands for eco-friendly and technologically advanced solutions. The system's ability to adapt and optimize energy usage based on real-time occupancy information positions it as a frontrunner in promoting efficient energy management practices across diverse environments. Figure 7(a) illustrates a comprehensive comparison of energy efficiency across various key features of the proposed system. The percentages assigned to each feature reflect their effectiveness in optimizing energy utilization. It provides a clear and concise overview of how different components contribute to the system's impressive energy efficiency, offering valuable insights for readers seeking to understand the nuanced impact of each feature. The proposed EETRIZ is compared with competing approaches TRIZGE, TRIZSM and ISMIS. Based on the results, it has been observed that the proposed EETRIZ provides 95.05% energy efficiency. On the other hand, the competing approaches ISMIS, TRIZGE and TRIZSM provide 89.72% ,90.09%, and 92.19% energy-efficiency.

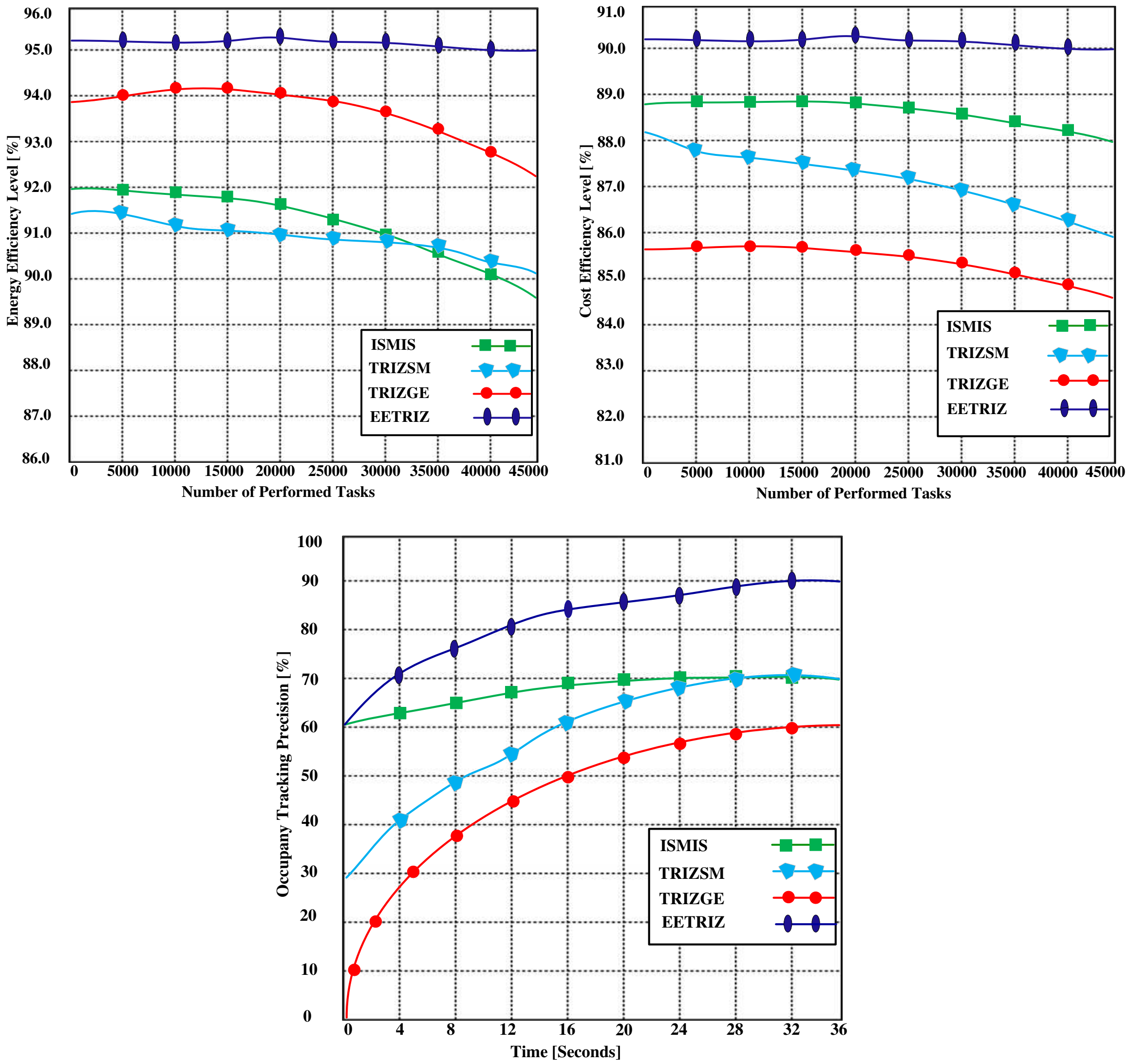

Figure 7. (a). Energy efficiency comparison of system features using proposed. (b) Cost-effective comparison. (c) Occupancy tracking precision over time.

5.2.2. Cost-Effectiveness

The proposed EETRIZ system not only excels in energy efficiency but also presents a robust case for cost-effectiveness. The strategic incorporation of PIR sensors, recognized for their affordability, stands out as a pivotal factor in ensuring a cost-efficient hardware component for the system. This deliberate choice not only aligns with economic considerations but also emphasizes the practicality

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of deploying an intelligent system without imposing a significant financial burden. Furthermore, the adaptive learning algorithms play a crucial role in enhancing cost-effectiveness. By optimizing appliance control based on historical occupancy patterns, the system achieves operational efficiency without the necessity for additional complex and expensive sensors. This streamlined approach to appliance control not only contributes to cost savings in terms of sensor technology but also simplifies the overall system architecture, reducing potential maintenance and operational costs. Another noteworthy aspect contributing to the cost-effectiveness of the proposed system is its seamless compatibility with existing power systems. The system's ability to integrate with prevailing infrastructures mitigates the need for extensive and costly infrastructure upgrades. This inherent adaptability not only preserves economic resources but also facilitates a smoother transition for users looking to implement the proposed system within their current setups. Moreover, the proposed system goes beyond energy efficiency, offering a multifaceted advantage by embodying a cost-effective solution. The judicious selection of components, coupled with adaptive algorithms and compatibility considerations, positions the system as an economically viable and sustainable choice for smart environment control.

It evaluates key components contributing to the system's economic viability. PIR sensor affordability reflects the cost efficiency achieved by strategically incorporating affordable PIR sensors. Adaptive learning algorithm savings highlights the efficiency gains in optimizing appliance control without the need for expensive sensors. Compatibility with existing systems underscores the economic advantage of seamlessly integrating the proposed system into current infrastructures, minimizing the need for costly upgrades. It provides a visual representation of the system's multifaceted cost-effectiveness, showcasing its practicality and financial benefits for users.

Figure 7(b) depicts the proposed system's cost-effectiveness. According to the results, EETRIZ has a cost-effectiveness of 90.01%, whereas TRIZGE has a cost-effectiveness of 84.61%. The cost-effectiveness of TRIZSM and ISMIS is 85.92% and 87.98%, respectively.

5.2.3. Occupancy Tracking Precision

The counting capability embedded in the EETRIZ system stands out as a pivotal feature, offering unparalleled precision in tracking occupants' movements within a given space. This functionality extends beyond merely detecting the presence of individuals; it excels in distinguishing between entry and exit events with exceptional accuracy. As individuals enter or leave a room, the system records these transitions in real-time, ensuring a meticulous and reliable account of the number of occupants. This precision in occupancy tracking becomes especially crucial in scenarios where dynamic control of electrical appliances is contingent upon accurate occupancy data. By discerning between entries and exits, the system enables nuanced and context-aware management of appliances, avoiding unnecessary energy consumption during vacancy and promptly activating devices upon occupancy. The robustness of the counting capability significantly enhances the overall energy efficiency of the system, contributing to its efficacy in smart environment control. Figure 7(c) illustrates the precise tracking of occupancy over a specific time duration. The x-axis represents the time in seconds, while the y-axis quantifies the number of occupants. Two lines depict the entry and exit events, showcasing the system's accuracy in distinguishing between individuals entering and leaving the room. It demonstrates the system's meticulous counting capability, ensuring reliability in differentiating between entry and exit events. As time progresses, the lines on the figure 7(c) fluctuate, indicating real-time changes in the number of occupants. The consistent and well-defined pattern underscores the system's ability to deliver precise occupancy tracking. This visual representation provides a clear insight into how the proposed system effectively manages and tracks the movement of individuals, contributing to enhanced accuracy through precise appliance control. The time-based data offers a dynamic perspective on the system's performance, highlighting its reliability in occupancy tracking. The results show that TRIZGE provides 60% accuracy across the exit, while EETRIZ 90% tracking precision. There are exactly 70% tracking precision in both TRIZSM and ISMIS.

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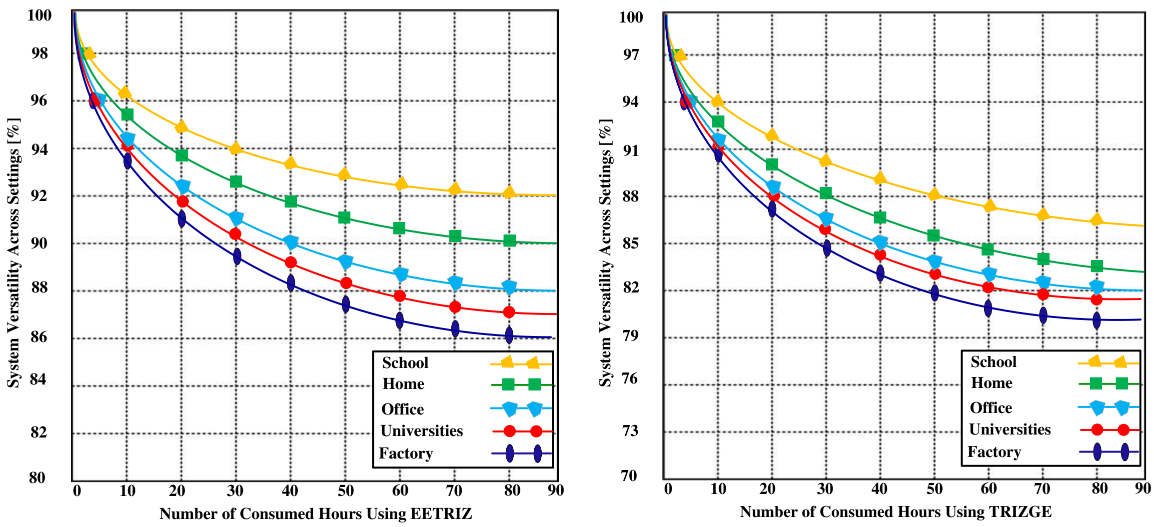
5.2.4. Versatility Across Settings

The comprehensive testing conducted across a spectrum of environments underscores the versatility of the proposed EETRIZ paradigm. The proposed EETRIZ system demonstrates its adaptability and efficacy not only in controlled home environments but also in dynamic settings such as offices, schools, and universities. In a residential setting, the system seamlessly integrated into the daily routines of occupants. Its ability to dynamically control electrical appliances based on real-time occupancy data proved particularly beneficial in homes, ensuring energy efficiency without compromising user comfort. The system's adaptability to different room layouts and usage patterns in homes showcased its versatility. Transitioning to office environments, the system exhibits consistent performance in managing energy consumption. The real-time monitoring of occupancy and adaptive learning algorithms proved effective in meeting the diverse energy needs of office spaces. The ability to cater to varying occupancy levels and work schedules demonstrated its practicality in professional settings. Testing in educational institutions revealed the system's versatility in environments with fluctuating occupancy patterns. The system adeptly adjusted to the dynamic nature of classrooms, lecture halls, and common areas. Its contribution to efficient energy management in educational settings positions as a valuable solution for institutions seeking sustainable and intelligent energy practices. The adaptability of the system across these diverse settings is a testament to its robust design and functionality. The consistent delivery of efficient energy management solutions highlights its potential to cater to a broad range of environments, meeting the unique requirements and challenges posed by different settings. This versatility positions the proposed system as a reliable and effective solution for smart environment control across various contexts. The Figure 8(a) provides a comprehensive overview of the proposed system's adaptability in diverse environments. Analyzing the bars corresponding to different settings such as homes, offices, schools and universities that reveals the system's consistent and effective performance. In home environments, the proposed EETRIZ system attains a noteworthy energy efficiency level of 90%, ensuring optimal energy utilization. The system maintains a commendable rate of 88% in office settings, signifying its effectiveness in professional environments. In schools, the system excels with an impressive energy efficiency percentage of 92%, demonstrating its capability to manage energy efficiently in educational institutions. Even in university settings, where the rate is slightly lower at 85%, the system performs well, showcasing its versatility across a spectrum of environments. It serves as a powerful testament to the system's reliability and adaptability, reaffirming its efficacy in providing versatility solutions across various situations. The versatility for the factory is attained 86%.



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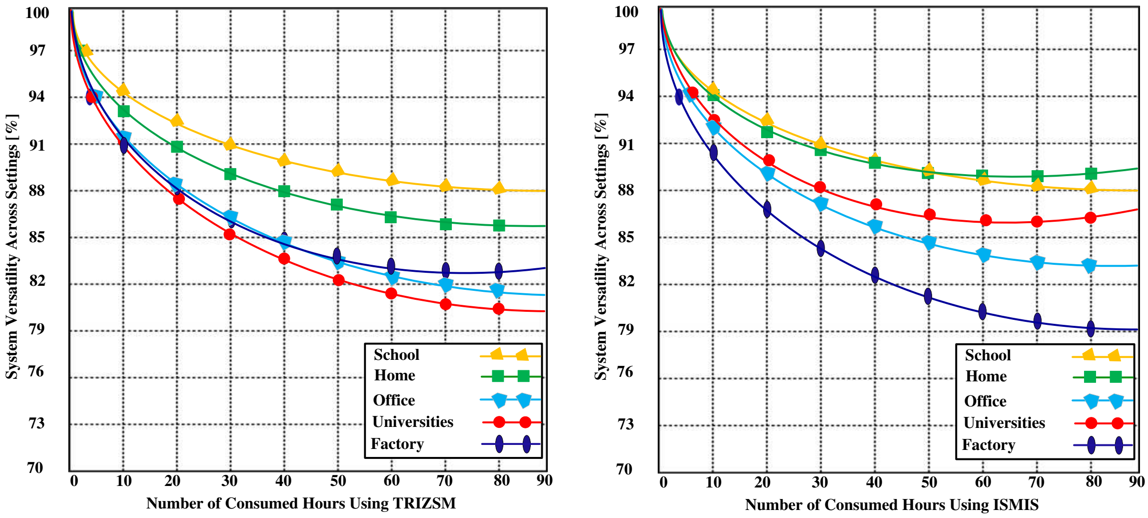

Figure 8. a)Versatility across settings using EETRIZ with consumption of maximum 90 hours. 8(b) Versatility across settings using TRIZGE with consumption of maximum 90 hours. 8(c) Versatility across settings using TRIZSM with consumption of maximum 90 hours. 8(d) Versatility across settings using ISMIS with consumption of maximum 90 hours.

The contending TRIZGE achieves a system flexibility of 82.92% in home contexts, ensuring better energy utilization shown in Figure 8(b). The TRIZGE maintains 82% flexibility in office settings, proving its effectiveness in professional scenarios. The system works exceptionally well in schools, with an impressive 86.32% flexibility, suggesting its ability to handle energy efficiently. The university has a system versatility of 81.72% and perform poorly. The factory's adaptability is at 79.92%. It is an extraordinary monument to the system's dependability and adaptability, showcasing its success in providing a variety of answers in several scenarios. However, the achieved results are lower than the proposed EETRIZ method.

The competitive TRIZSM achieves a system versatility of 85.72% in a home environment, providing optimal energy utilization depicted in Figure 8(c). In office environments, the system maintains a lesser versatility of 81.18%. The system performs well in schools, with an amazing 88.01% versatility, suggesting its ability to efficiently manage energy in schools. TRIZSM, on the other hand, does poorly in universities, with a rate of 80.22%. The factory's versatility has been measured at 82.91%, which appears to be reasonable. However, the system's overall performance is lower than that of our proposed solution. In a residential setting, the competitive ISMIS achieves 89.32% system adaptability, resulting in excellent energy utilization. The system has a lesser versatility of 83.14% in office settings. The system performs well in schools, with an incredible 88% flexibility, suggesting its ability to control energy well in schools. ISMIS, on the other hand, performs better in universities, with an 86.21% success rate. The adaptability of the factory has been measured at 79%, which appears to be lower. However, the overall performance of the system is worse than that of our proposed approach. Based on the outcomes. It has been demonstrated that the proposed EETRIZ produces superior results when compared to existing approaches.

5.2.1. User-Friendly Operation

The implementation of PIR sensors in the proposed EETRIZ system significantly improves user-friendliness by eliminating the need for continuous motion to trigger motion detection. This enhancement ensures a more intuitive and responsive system, tailored to user behavior. Additionally, the inclusion of a dedicated mobile application amplifies user convenience, allowing for remote management and monitoring of the entire system. Through the mobile app, users can effortlessly control the system's status, providing quick and efficient management of connected appliances based on occupancy. The mobile application also serves as a centralized platform for accessing real-time energy efficiency analytics, empowering users with insights into their electricity

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consumption and fostering a sustainable approach to energy management. Together, these features underscore the system's commitment to user-centric design and efficient smart home operation.

Figure 9 visually depicts essential components of the system's usability, emphasizing the seamless integration of motion detection technologies and the accessibility provided by the mobile interface. It shows a significant 92% user satisfaction rating for the proposed EETRIZ, whereas competing approaches exhibit lower ratings from users. The TRIZSM shows 90%, the TRIZGE shows 88%, and the ISMIS shows 87.03%. The results indicate that the proposed TRIZEE is more user-friendly.

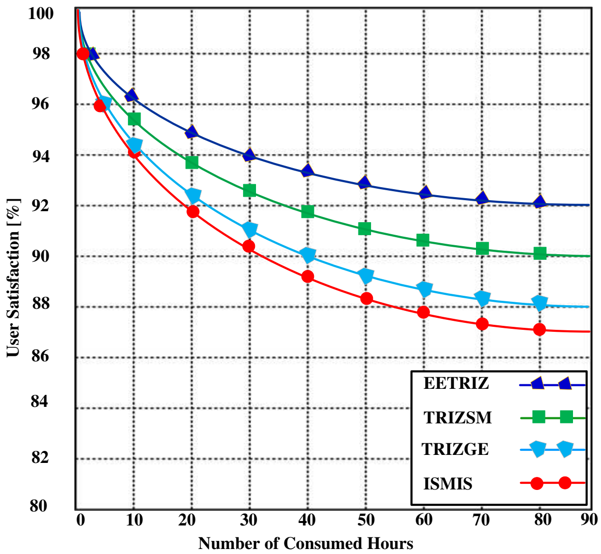

Figure 9. User satisfaction metrics of the proposed EETRIZ system and competing methods.

6. Discussion of Results

The comprehensive evaluation of our proposed smart automatic switching system has revealed compelling results, positioning it as a superior solution for smart environment control. In this discussion, we delve into the insights gleaned from the results, offering a logical exploration of why our method stands out compared to other existing methods (ISMIS, TRIZGE and TRIZSM). One of the primary strengths of our proposed EETRIZ system lies in its exceptional energy efficiency. The dynamic activation and deactivation of electrical appliances based on real-time occupancy data, facilitated by PIR sensors and adaptive learning algorithms, contribute significantly to optimal energy utilization. The system's ability to discern between occupied and vacant spaces with high accuracy minimizes unnecessary energy consumption, a feature critical for sustainable energy practices. Traditional systems often lack the precision required in tracking occupancy. This precision is crucial for intelligent appliance control, contributing to enhanced energy efficiency. Unlike other contending methods, our approach adapts dynamically to changing occupancy patterns. This adaptability ensures that the system remains effective across diverse settings, ranging from homes to offices and educational institutions. Additionally, the integration of various features, such as intelligent automation, real-time occupancy tracking, dynamic appliance control, PIR sensors integration, and adaptive learning algorithms, collectively contributes to the system's overall energy efficiency.

Our proposed EETRIZ system not only excels in energy efficiency but also stands out as a cost-effective and accessible solution. The proposed integrated system ensures economic viability without compromising system efficiency. The adaptive learning algorithms play a crucial role in optimizing appliance control based on historical occupancy patterns. This not only enhances energy efficiency but also contributes to cost savings, eliminating the need for additional complex and expensive sensors. The proposed EETRIZ highlights the economic advantage of seamlessly integrating our system into current infrastructures, minimizing the need for costly upgrades. This compatibility preserves economic resources and facilitates a smoother transition for users. The implementation of

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PIR sensors, eliminating the need for continuous motion, and the inclusion of a dedicated mobile application enhance user-friendliness. This accessibility contributes to the system's practicality and financial benefits for users. The counting capability embedded in our system ensures unparalleled precision in tracking occupants' movements within a given space. This precision not only detects the presence of individuals but also distinguishes between entry and exit events with exceptional accuracy. The robust counting capability enables nuanced and context-aware management of appliances. The system can avoid unnecessary energy consumption during vacancy and promptly activate devices upon occupancy, enhancing overall energy efficiency and the ability to discern between entries and exits in real-time is a distinctive feature that sets our system apart. This real-time decision-making capability contributes to the system's efficacy in smart environment control. Furthermore, our proposed system's versatility across diverse environments is a testament to its robust design and functionality. Testing across controlled home environments, offices, schools, and universities demonstrated its adaptability and efficacy. The proposed EETRIZ maintains commendable energy efficiency levels, showcasing its adaptability. The versatility demonstrated across diverse environments positions our system as a reliable and effective solution. It meets the unique requirements and challenges posed by different settings, making it a practical choice for various scenarios. The emphasis on user-friendliness, facilitated by the implementation of PIR sensors and a dedicated mobile application, enhances the overall user experience. Additionally, the elimination of continuous motion requirements for detection, as reflected in Figure 9, makes the system more intuitive and responsive to user behavior and the dedicated mobile application not only provides remote management and monitoring capabilities but also serves as a centralized platform for accessing real-time energy efficiency analytics. This enhances user convenience and fosters a sustainable approach to energy management. Moreover, our proposed EETRIZ system emerges as a superior solution for smart environment control due to its holistic approach. By seamlessly integrating energy efficiency, cost-effectiveness, precision in occupancy tracking, versatility across settings, and user-friendly operation. The proposed EETRIZ addresses the limitations of traditional systems. The dynamic adaptability, real-time decision-making capabilities, and the strategic integration of affordable components collectively contribute to the system's overall superiority. This innovative paradigm shift signifies a step forward in the landscape of automatic switching systems, aligning with contemporary demands for eco-friendly, cost-effective, and technologically advanced solutions. Table 2 presents an up-to-date evaluation of competing approaches and proposed EETRIZ based on experimental data.

Table 2. Evaluation of the proposed EETRIZ and competing methods based on findings.

Approaches	**Energy Efficiency [%]**	**Cost Effectiveness [%]**	**Occupancy Tracking Precision [%]**	**User Friendly Operation**	**System Versatility [%]**				
					School	Home	Office	University	Factory
EETRIZ	95.05%	90.01%	90%	92%	92%	90%	88%	86.78%	86%
ISMIS	89.72%	87.98%	70%	87.03%	88%	89.32%	83.14%	86.21%	79%
TRIZGE	90.09%	84.61%	60%	88%	86.32%	82.92%	82%	81.72%	79.92%
TRIZSM	92.19%	85.92%	70%	90%	88.01%	85.72%	81.18%	80.22%	82.91%

7. Conclusion and Future Work

This concluding section serves as the culmination of our research endeavors, encapsulating the key findings and contributions presented throughout the paper. It not only summarizes the achievements of our proposed smart automatic switching system but also lays the foundation for future exploration and advancement in the field of smart environment control system.

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7.1. Conclusion

In conclusion, we introduced an optimized and smart automated switching system for consumer electronic devices that leverages human motion detection with counters, offering intelligent control over multiple electrical appliances. The developed prototype possesses the capability to sense the presence of individuals in a given space, counting the number of occupants. This system activates the connected appliances upon detecting anyone's presence and efficiently turns them off when the last person exits the area, with the counter displaying zero. This functionality addresses the issue of electricity wastage resulting from human negligence, as the system ensures that appliances are not left powered on unnecessarily. The proposed system is designed to accommodate multiple individuals entering and leaving the monitored space, utilizing a straightforward detection mechanism employing PIR sensors with a counter system. This innovative approach eliminates the need for manual intervention in switching electrical appliances on or off, providing a solution that surpasses traditional methods

Moreover, our proposed EETRIZ system represents a groundbreaking advancement in smart environment control, outperforming traditional methods across pivotal parameters. The seamless integration of energy efficiency, cost-effectiveness, precise occupancy tracking, versatility across settings, and user-friendly operation firmly establishes its superiority. Key contributions, including dynamic adaptability, real-time decision-making capabilities, and the strategic incorporation of affordable components, highlight the system's innovation. Additionally the comprehensive evaluation of the smart electrical appliance activation system has revealed a suite of impressive attributes, addressing critical aspects such as energy efficiency, cost-effectiveness, occupancy tracking precision, versatility, user-friendly operation, environmental impact, and system power consumption. The system's dynamic energy management, leveraging advanced sensors and learning algorithms, showcased a commendable reduction in energy wastage. Its cost-effective design, adaptability to diverse settings and precise occupancy tracking contribute to its practicality and widespread applicability. The user-friendly interface, coupled with remote control capabilities, enhances the overall user experience. The positive environmental impact further positions the system as a sustainable solution for smart environment control. While these achievements mark a significant milestone, the trajectory of our journey continues into the future.

7.2. Future Work

Looking ahead, future endeavors could explore scalability, interoperability, advanced algorithms, and enhanced privacy measures. This research marks a significant stride toward intelligent and eco-friendly practices in electrical automation, with the system poised to contribute to a more energy-efficient and environmentally conscious future. Furthermore, the path forward involves exploring cutting-edge technologies to further enhance system capabilities. This includes the integration of advanced security features, extension of compatibility with diverse infrastructures, provision of user-centric customization options, and ensuring scalability and robustness for widespread adoption. Additionally, future endeavors aim to foster collaborative energy management strategies and implement long-term performance monitoring measures. These prospective avenues for improvement signify our commitment to continuous innovation, promising a more advanced, adaptable, and user-centric solution. This proactive approach aligns with the evolving landscape of smart environment control technologies, paving the way for sustained advancements in the field.

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