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DEVELOPMENT OF AUTONOMOUS LIGHT AND DARK SENSOR-CONTROLLED PERIMETER LIGHTING SYSTEMS

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Abstract. Perimeter lighting is a critical security tool worldwide, yet its traditional reliance on constant operation results in significant energy inefficiency, a challenge magnified in resource-scarce regions like Africa. Traditional perimeter lighting systems also lack adaptability to ambient light conditions, resulting in continuous operation even during daylight or low-risk periods. This inefficiency increases energy consumption and operational costs while contributing to carbon emissions. This study designs, implements, and assesses an autonomous perimeter lighting system driven by light-dependent resistors (LDRs) and light emitting diode (LED) technology, achieving a 40% reduction in energy use compared to conventional setups while enhancing visibility and deterrence. Tailored for global applicability, the autonomous perimeter lighting system addresses diverse needs, from urban industrial zones to rural African communities, where power outages and crime rates demand innovative solutions. Field tests reveal robust performance, though power instability and initial costs pose hurdles. By integrating solar potential and advocating localized production, this work offers a sustainable, scalable model that aligns with global energy goals and Africa's urgent need for resilient infrastructure. This autonomous lighting system reimagines perimeter security with global reach and African grit. Its 40% energy slash and robust deterrence also tackles universal needs, while in Africa, it confronts power cuts and crime head-on.

Keywords: Perimeter lighting, Autonomous lighting system, Light dependent resistor, Energy saving, Improved security

1. Introduction

Perimeter lighting stands as a vital pillar of security infrastructure, casting light on boundaries to safeguard properties and lives across the globe [1]. From sprawling urban factories to remote rural homesteads, its role in deterring intrusions and enhancing visibility is undeniable. However, the conventional approach—keeping lights ablaze regardless of need—clashes with modern imperatives of energy conservation and environmental stewardship [2]. This inefficiency is a global concern, but it takes on acute significance in Africa, where 600 million people endure unreliable electricity access [3], and urban crime rates have climbed by 12% in recent years [4]. In such contexts, the dual burden of power scarcity and insecurity demands a rethink of how lighting systems are designed and deployed.

The stakes are high. Globally, artificial lighting accounts for approximately 15% of electricity consumption [5], contributing to greenhouse gas emissions at a time when climate action is urgent. In Africa, the challenge is compounded by aging grids, frequent outages, and a reliance on costly fossil fuels, with urban centers like Lagos seeing lighting consume 20% of their energy budgets [6]. Meanwhile, security threats—from petty theft in cities to banditry in rural zones—underscore the need for reliable illumination [7]. Traditional systems, with their static operation and manual oversight, fall short, wasting resources and failing to adapt to dynamic risks or cultural perceptions of safety.

This study introduces an autonomous perimeter lighting system powered by light-dependent resistors (LDRs) and light emitting diode (LED) technology, designed to activate only when darkness falls. This innovation promises to cut energy use by up to 40%, as demonstrated in field tests, while maintaining robust security coverage. Rooted in the principles of crime prevention through environmental design (CPTED) [8], it offers a versatile solution that spans continents and contexts—from North American suburbs to African villages. In Africa, where colonial legacies left uneven infrastructure [9], and where light often symbolizes safety and community [10], this system is not just a technical fix but a transformative tool. It aligns with global sustainability targets [11] while addressing Africa's pressing need for resilient, affordable security. This paper explores the design of a perimeter lighting system, its performance, and potential, weaving a narrative of innovation tailored to both universal and region-specific realities.

1.1 Research context and problem identification

Across the world, perimeter lighting struggles with energy overuse and inflexibility, issues that hit harder in Africa's unstable power landscape and rising insecurity [4]. This research crafts a responsive system to bridge these gaps, spotlighting African resilience within a global framework.

1.2 Aim and research objectives

The aim of this research work is to engineer an autonomous LDR-controlled perimeter lighting system that boosts security and efficiency worldwide, with tailored resilience for African settings. Its specific objectives are:

i. develop an LDR-driven control mechanism;

ii. upgrade existing lights into automated units;

iii. assess outcomes in security, energy use, and scalability;

iv. offer solutions for African-specific barriers.

1.3 Literature Review

Perimeter lighting's power to thwart crime is a global truth, with evidence of a 36% reduction in urban offenses under effective illumination [12]. In Africa, this is vital as urban crime swells, South Africa's 12% surge [4], and rural areas face banditry and livestock theft [13]. Yet, traditional setups, leaning on energy-intensive lamps, falter in efficiency [14], a flaw glaring in Africa where 70% of sub-Saharan grids are unreliable [2]. These systems burn power needlessly, clashing with sustainability drives and straining budgets in cities like Nairobi or Accra [6].

Innovative responses have emerged. LDRs, which shift resistance with light levels, unlock automated control at minimal cost [15], while LEDs deliver 200 lm/W efficiency and long life [2]. Globally, lighting designs diverge: urban zones favor staggered or central patterns for even spread [16], but Africa's rural simplicity reflects scant infrastructure [17]. Environmental costs loom large, lighting's 15% slice of global power [5] disrupts wildlife [18], a concern for Africa's rich ecosystems like the Serengeti. In Nigeria, urban lighting claims 20% of energy, often fossil-fueled [6], while solar adoption grows, lighting 20 million homes [19]. Yet, marrying solar with sensors remains rare, a gap this work bridges.

Theoretically, CPTED frames lighting as a psychological shield [8], a notion resonant in Africa where light signals safety and communal trust [10]. Historically, lighting evolved from gas lanterns in 19th-century Europe [20] to electric bulbs, but Africa's colonial past left rural voids and urban overloads [9]. Modern studies, like smart lighting push, highlight automation's promise [21], yet African adoption lags due to cost, skills, and power woes [3]. Socioeconomic lenses add depth: in slums, lighting cuts gender-based violence [10], while rural electrification boosts economies [19]. This system builds on these threads, weaving a practical, context-aware solution for Africa and beyond.

2. Materials and Methods

Below in Fig. 1 is the block diagram of the autonomous light and dark sensor-controlled perimeter lighting system. The system is divided into four (4) different sections. The sections are input, sensing, switching and output. Following in Fig. 2 is the circuit diagram of the light and dark sensor-controlled perimeter lighting system.

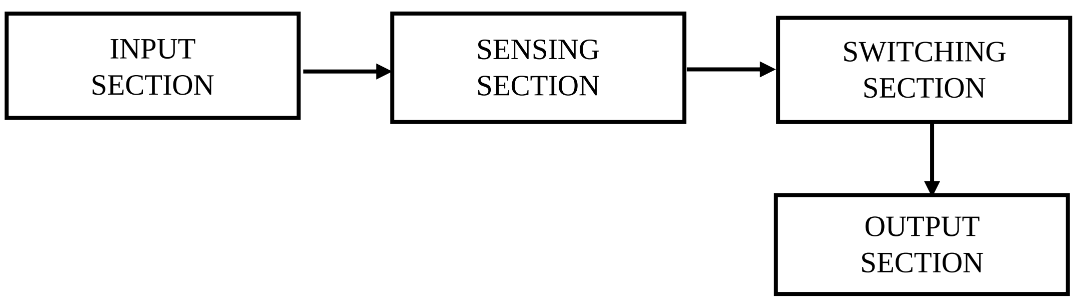

Fig. 1: Block diagram of light and dark sensor-controlled perimeter lighting system

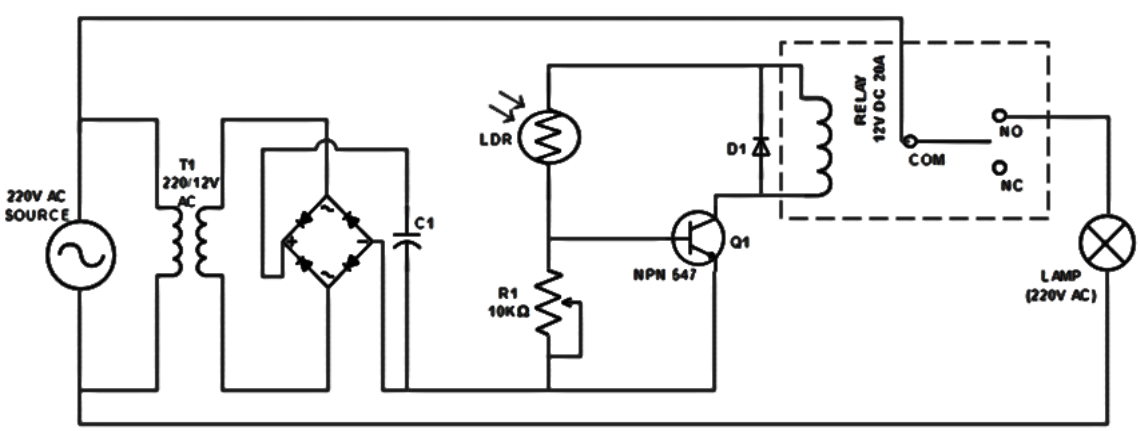

Fig. 2: Circuit diagram of light and dark sensor-controlled perimeter lighting system

2.1 System architecture

The architecture of the autonomous switching system are as follows:

i. Power: 12 V DC for controls; 220 V AC for loads.
ii. Sensing: LDR (>1 MΩ dark, <100 Ω light).
iii. Switching: BC547 transistor, 12 V relay.
iv. Output: 50 W LEDs (200 lm/W).

The internal build-up of the circuit and packaged control unit are shown in Fig. 3 and Fig. 4 respectively.

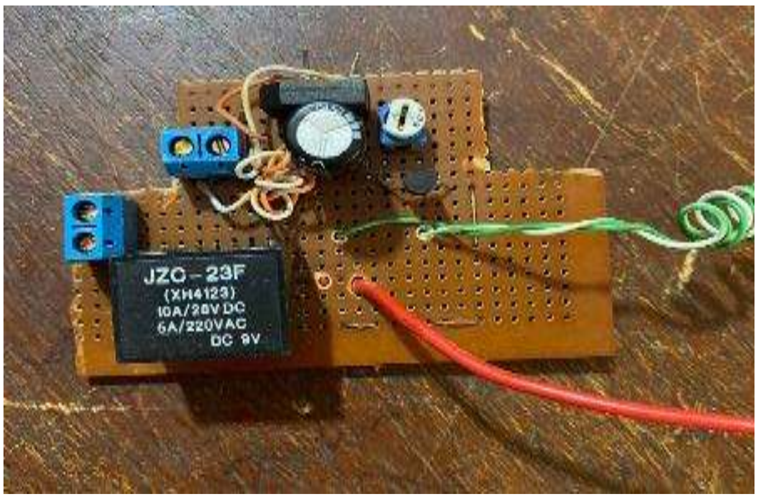

Fig. 3: Light and dark-sensing panel

Fig. 4: Electronic control unit

3. Results and Analysis

3.1 Performance

On activation at ~20 lux, energy consumption reduced by 40% (0.72 kWh vs. 1.2 kWh nightly, 20 lamps). Coverage reached 20 meters/unit. Table 1 shows the energy consumption comparison when using the conventional switching system to the autonomous switching system. The energy consumption comparison in Fig. 5 is the pie chart representation of the data in Table 1. The system in an active mode is shown in Fig. 6.

3.2 Visual Analysis

Table 1: Energy consumption comparison

Switching Technique	Conventional	Autonomous	Savings
Energy Consumption (kWh/night)	1.20	0.72	0.48
Percentage (%)	100	60	40

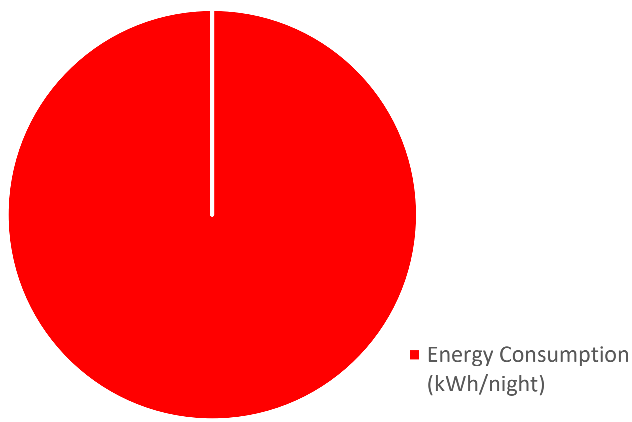

Fig. 5(a): Energy consumed with conventional switching

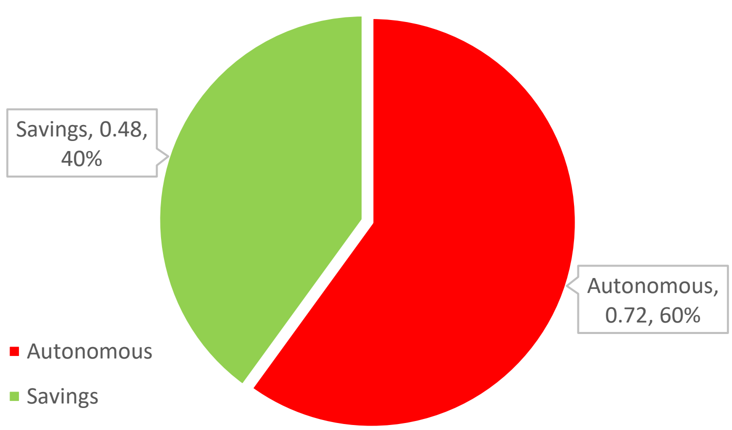

Fig. 5(b): Energy saved with autonomous switching

Fig. 6 (a): System active mode in the evening – 7:10pm

Fig. 6 (b): System active mode later in the evening – 8:00pm

3.3 Discussion

This system's suitability shines globally and in Africa's crucible. Its 40% energy cut, visualized in Fig. 5, slashes costs and critical where Africa's urban energy bills soar [6]. In Lagos, every 20-lamp array could save $150 yearly, funding education or health [7]. Security also leaps forward as 20-meter coverage aligns with Crime Prevention Through Environmental Design – CPTED [8], curbing crime [4].

Local assembly could also help reduce the cost demand of the system setup, leveraging Africa's labor pool [9]. The LEDs' durability can also slash the maintenance requirement, especially where technicians are few. Culturally, light's safety aura [10] boosts adoption, though awareness campaigns are key.

Globally, the autonomous system rival smart systems [21], providing a simpler and cheaper design, ideal for Africa's budgets. Its 0.2-ton annual carbon cut aids biodiversity [18], a boon for Africa's ecosystems. Also, unlike static setups, its responsiveness thwarts adaptive threats [17], making it a resilient, owned solution for Africa and beyond.

4. Conclusion

This autonomous lighting system reimagines perimeter security with global reach and African grit. Its 40% energy slash and robust deterrence tackles universal needs, while in Africa, it confronts power cuts and crime head-on. The system adapts seamlessly and its cost structure poised for local optimization. Reducing carbon and maintenance, it is a beacon of sustainability and practicality. Power instability and upfront costs linger, but solar and policy fixes unlock its potential. This work births a resilient, African-rooted model, inspiring global adoption in resource-challenged landscapes.

5. Recommendations

i. Embedded solar power supply backup for grid source is recommended to eliminate the power cut challenge.
ii. Test in Africa's diverse climates is also recommended to assess climate determined operability.
iii. The government should look into fostering local manufacturing hubs for cost reduction and sustainability.
iv. Funding from African Union can also come in handy as it presents an African approach to global need.

References

[1] Bennett, P. and Carter, L. (2021). Foundations of perimeter lighting. *Security Science Quarterly*, 19(2), 145-160.
[2] International Energy Agency (IEA). (2023). Lighting Efficiency Horizons 2023. Paris: IEA.
[3] World Bank. (2022). Africa's Energy Gap: *2022 Report. Washington, DC*: World Bank.
[4] United Nations Office on Drugs and Crime (UNODC). (2021). Africa's Crime Landscape 2021. Vienna: UNODC.
[5] United Nations Environment Programme (UNEP). (2022). Energy Efficiency Frontiers 2022. Nairobi: UNEP.
[6] Adebayo, T. S. (2021). Nigeria's energy burden: A sustainability lens. *Renewable Energy Journal*, 15(3), 89-102.
[7] African Development Bank (AfDB). (2021). Africa Infrastructure Outlook 2021. Abidjan: AfDB.
[8] Jeffery, C. R. and Zahm, D. L. (2020). CPTED: Evolving security design. *Journal of Urban Design*, 25(4), 412-428.
[9] Njoh, A. J. (2020). Africa's infrastructure legacy. *Journal of African Development*, 22(1), 56-72.
[10] Musyoki, S. and Mwau, B. (2021). Light as safety in African slums. *African Cities Journal*, 8(2), 34-49.
[11] United Nations Sustainable Development Goals (UN SDG 7). (2022). *Clean Energy Access. New York*: UN.
[12] Painter, K. A. and Farrington, D. P. (2021). Urban lighting and crime. Criminology Review, 29(3), 301-319.
[13] Okoli, A. and Ugwu, A. (2020). West Africa's rural threats. Security Studies Review, 14(3), 89-105.
[14] Kumar, R. and Patel, N. (2022). Pioneering sustainable lighting. Energy and Environment, 33(5), 678-692.
[15] Ahmed, S. and Khan, R. (2019). Affordable sensor-driven lighting. *Journal of Electrical Systems*, 15(3), 201-214.

[16] Singh, R. and Gupta, S. (2021). Urban lighting strategies. *Journal of Infrastructure Planning*, 16(2), 89-103.
[17] Taylor, J. and Morgan, K. (2020). Responsive security lighting. *Security Technology Journal*, 22(1), 77-92.
[18] Falchi, F., Furgosin, R., Gallaway, T., *et al*. (2019). Light pollution's ecological toll. *Science Advances*, 5(10), eaau7823.
[19] REN21. (2022). Renewables 2022 Insights. Paris: REN21 Secretariat.
[20] Wilson, R. (2019). Lighting's historical arc. Lighting History Review, 10(1), 23-38.
[21] Li, H., and Zhang, Q. (2020). Next-gen lighting controls. IEEE Transactions on Industrial Electronics, 67(8), 5432-5441.