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Short message system-enhanced occupancy adaptive lighting system with real-time overcrowding control

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Abstract

The traditional indoor lighting systems are unnecessary since they use energy to light up fully regardless of the presence of occupants. This paper introduces a lighting system based on microcontroller, which can dynamically regulate light based on the occupancy in real-time and provide alerts in case of overcrowding in the room. The prototype will have four ultrasonic sensors and a door-mounted reed switch to count the occupancy in both directions, which will be controlled by an Arduino Uno controller. The lighting level is controlled by pulse-width modulation and a GSM module is used to send SMS notifications when the occupancy level is surpassed. The system was evaluated experimentally in a 4 x 4m controlled environment to compare its performance to that of a fixed-output lighting system. Findings indicated that the mean detection accuracy of 200 trials was 92 percent and the average energy saving was 45 percent with a maximum saving of 62 percent when it was lowly occupied. Alerts on overcrowding came in less than 1.2 seconds, which was in line with real-time responsiveness. It has been shown that cost-effective and edge-based platforms are able to provide effective lighting control and occupant safety monitoring functionality without relying on a cloud platform or sophisticated networking infrastructure.

Nomenclature and units

N_{OCC}	Number of occupants detected in the room
N_{th}	Occupancy threshold for overcrowding detection
d_i	Raw distance measured by ultrasonic sensor *i*
$\bar{d}_i$	Filtered distance measurement from ultrasonic sensor *i*
d_{th}	Distance threshold for presence detection
β	Exponential smoothing coefficient
α	PWM duty cycle for lighting control
K	Gain factor for lighting energy conservatism
t_s	Sensor sampling interval
L_{min}	Minimum allowable illuminance
L_{max}	Maximum allowable illuminance

1.0 Introduction

The built environment is becoming an important area of concern regarding sustainable engineering due to rapid urbanization, a rising rate of energy consumption, and increased complexity of building services (Munonye & Ajonye, 2025; Antonio et al., 2024). The global status report on buildings and construction of 2024 indicates that operational energy consumption in buildings represents approximately 30 percent of the overall final energy use in the world, and lighting occupies 15-20 percent of electricity applications in commercial and residential structures (UNEP, 2025). The conventional lighting systems that are mainly based on manual operation or fixed time-based lighting control usually do not keep pace with the real occupancy patterns so that too much lighting is provided at times of low occupancy and too little lighting is provided at times of peak occupancy. These discrepancies create recorded energy wastage of 20-60% in uncontrolled areas (Wagiman et al., 2020; García-Martín et al., 2025; Abdulhussain et al., 2025). When combined with networked sensors and adaptive algorithms, occupancy-responsive light systems all-too-often report a 35-70 percent saving in the lighting energy use (Abdulhussain et al., 2025; Makanju et al., 2025). The technological base of early systems depended mainly on binary motion detection with passive infrared (PIR) sensors, which had cost savings but not granularity in a multi-occupant environment. Much more recent engineering studies have moved to the multi-sensor fusion and machine-learning techniques of fine-grained occupant enumeration and predictive control (Song & Calautit, 2025). As an illustration, an occupancy prediction algorithm enabled by CO2 in offices resulted in 85-95 price in workplace environments, allowing occupancy-related lighting-HVAC optimization with 25 percentage energy reductions (Kim et al., 2023; Anand et al., 2019). Complementary experiments that take advantage of Wi-Fi signal perturbations have shown that they can occupant track near-real time with quantifiable combined HVAC-lighting energy savings of approximately 6 % (Sharma et al., 2024). In addition to energy efficiency, the occupant safety and public-health concerns, which the COVID-19 pandemic has increased, have rendered overcrowding detection a similarly important design goal. Ultrasonic- or camera-based crowd counting has demonstrated a high accuracy of over 90 percent in enumerating entrances (Awada et al., 2022), and can be used to support real-time alerts that comply with the updated building-code requirements of ventilation and density control (Yu et al., 2025). Ultrasonic in particular, offer non-intrusive, line of sight independent measurement that is appropriate when resources are limited and privacy and cost are the driving factors (Aliew, 2022; Chukwu et al., 2023). These advancesnotwithstanding, there are still great gaps in engineering. There are numerous commercially-offered smart-lighting systems that rely on cloud computing to process their data, which adds latency and exposes them to network errors. Others are either expensive to install or are based on power-consuming sensor arrays, and thus cannot be used in small scale applications in developing areas with intermittent network connections. In addition, the number of affordable platforms that combine occupancy-adaptive lighting with GSM-based warning of an overcrowding incident and are still full-fledged in offline or edge-processing mode is relatively scarce (Adoghe et al., 2024). The current study attempts to resolve these issues, by coming up with and prototyping a smart lighting system to offer occupancy-responsive illumination and real-time overcrowding reduction. The system consists of ultrasonic occupancy sensors to measure the exact occupancy, door-state reed switch to measure the directional flow, a microcontroller-controlled relay to provide pulse-width-modulated (PWM) dimming of LED luminaires. Exceeding thresholds activate local audible/visual signals and short-message-service (SMS) notifications by using a low-cost GSM module, which does not require reliance on cloud infrastructure. Illuminance is also dynamically controlled to adhere to the IEEE/ASHRAE Standard 90.1-2022 to ensure comfort in visual perception and the highest possible rate of energy saving (Myer & Seeger, 2022). This work assesses the accuracy of detection, benefits in energy-efficiency, and responsiveness of systems when compared to state-of-the-art detection systems through experimental validation in a controlled 4m x 4m test environment. The proposed solution provides a scalable design of sustainable lighting control in residential, commercial and institutional buildings with a cost-effective, edge-computing architecture, a combination of energy management and occupant-safety capabilities, and have a high likelihood of functioning in affordable, reliable and low-network-reliance environments, especially in areas where affordability and reliability are paramount.

2.0 Materials and Methods

In this section, the system design and methodology for this research are presented.

2.1 *System Architecture*

The system proposed has a modular and microcontroller-based architecture, which is depicted in Fig. 1 (block diagram). In its very essence, it is an Arduino Uno, connecting to input sensors and actuators through the digital/analog pins. The sensors are ultrasonic (HC-SR04) installed at convenient positions in the room to record the distance echoes used to estimate the number of occupants with a range of 4m and a precision of +-3cm. The door sensor is a reed switch, which tracks ingress/egress and counts the directionality. Power is distributed through a 5V DC adapter that supplies power to the microcontroller and peripheral. Outputs consist of a relay to control LED lamps in PWM mode (mimicking the room lighting), a buzzer to provide audible notification, an LCD (16x2) to display on-site and a SIM800L GSM to send an SMS. Overcrowding is a condition of going over a set amount (e.g. 4 occupants) and declaring alerts to pre-established figures.

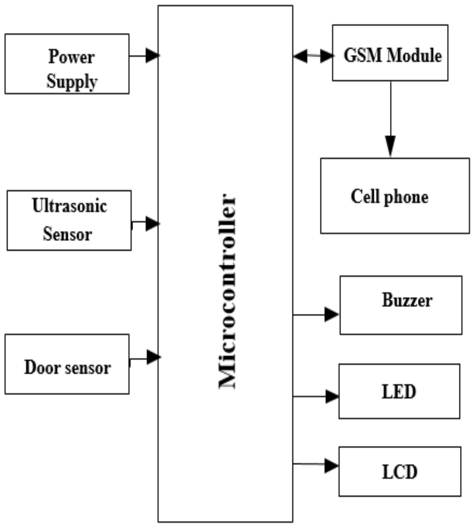

Figure. 1: Block diagram of the smart lighting system.

2.2 Occupancy Detection Algorithm

Figure 2 depicts a logic diagram based on a flowchart of occupancy using a state machine that is written in Arduino C++. The distance di of sensor i is obtained by ultrasonic measurements and converted to presence by a threshold dth = 200cm. The number of counts is either rising or falling with the state of the door:

$Nocc = \text{Nprev} + \Delta\text{D} \cdot \text{Su}$ .... (1)

Where:

ΔD = door delta (±1),

and Su aggregates ultrasonic detections (majority vote across four sensors).

A simplified recursive smoothing filter was used to increase resistance to spurious ultrasonic echoes and short-run noise in the measurements of distance that each ultrasonic sensor measures, using the raw distance measurements. The developed implementation, though based on the concepts of Kalman filtering, is a lightweight exponential smoothing filter that is easily suitable to operate in real-time on a resource-constrained microcontroller. For each sensor i, the filtered distance $\check{d}_i(K)$ at sampling instant k is computed as:

$\check{d}_i(K) = \beta d_i(k) + (1-\beta)\check{d}_i(k-1)$..........................(2)

where $d_i(k)$ is the instantaneous measured distance and $\beta \in (0,1)$ is the smoothing coefficient. In this implementation, $\beta = 0.6$ was selected empirically to balance responsiveness and noise suppression. This filtering eliminates the effect of false presence detection due to transient reflections or sudden motion, and provides enough temporal resolution to occupancy tracking in real time.

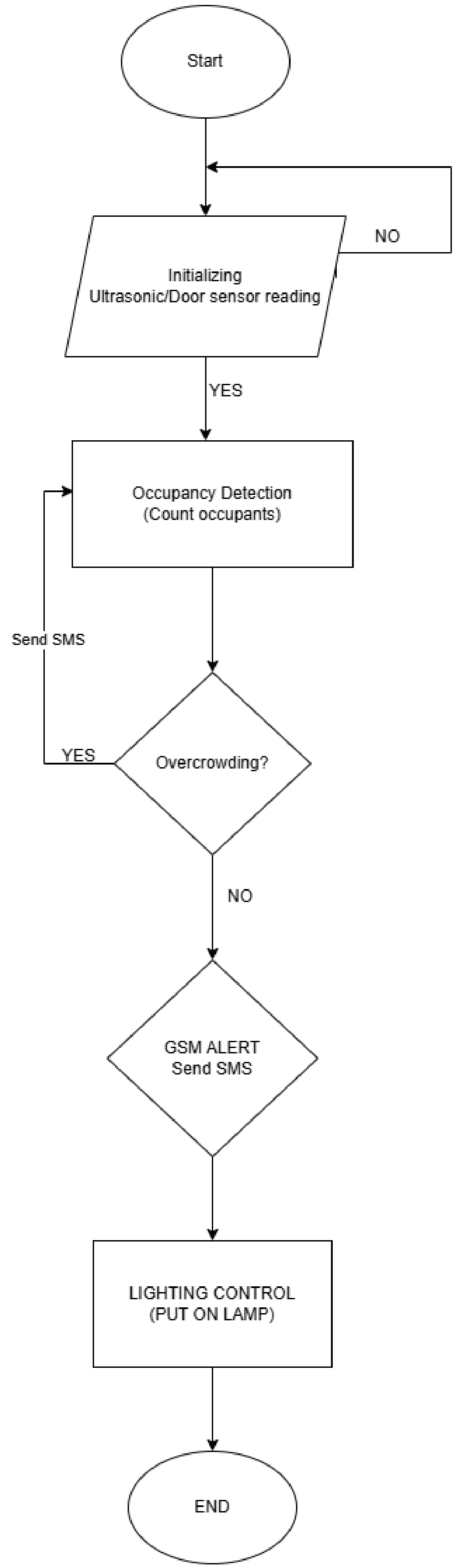

Figure 2: System flowchart for occupancy and lighting control.

The majority-vote fusion rule is used to determine occupancy presence among the four ultrasonic sensors. Individual sensors provide binary presence decisions as a result of a distance threshold $dth = 200cm$. A sensor reports presence if:

$$\tilde{d}_i \leq d_{th}$$

The general occupancy presence in a certain moment is assured when at least three out of four sensors identify presence at a certain moment. Such a hybrid approach reduces the occurrence of false positives caused by sensor-noise or partial-occlusion as well as spatial uniformity throughout the area being monitored. Directional occupancy count is then updated with the aid of door-mounted reed switch which increments or decrements the occupancy count depending on the ingress or egress events. Spatial sensor fusion and directional flow sensing combined are important because it enhances the accuracy of counting multi-occupants' situations.

2.3 Lighting Adaptation Mechanism

Illuminance $L\ (lux)$ scales linearly with $Nocc$, bounded by IEEE standards (Table 1). PWM duty cycle α drives the relay:

$$\alpha = \alpha \min + (\alpha \max - \alpha \min). \frac{Nocc}{Nth}.K \quad (3)$$

Where:

k = gain (0.8) for energy conservatism

Nth = 4, and bounds ensure 150-450 lux per Table 1.

Table 1: IEEE Recommended Lighting Standards in Lux

Lighting Levels	Places	Side Daylighting: Standard Values		Top Daylighting: Standard Values	
		of Daylight Coefficient (%)	of Indoor Natural Illuminance (lx)	of Daylight Coefficient (%)	of Indoor Natural Illuminance (lx)
III	Reading space open shelf	3.0	450	2.0	300
IV	Collection room	2.0	300	1.0	150
V	Stack room, walkway, staircase, toilet	1.0	150	0.5	75

The parameter of gain K in Equation (2) is a conservative scaling factor that attenuates the correlation between the number of occupants and the level of illuminance. K=0.8 was empirically determined in this study by testing the value until the illumination levels were maintained within the comfort range of limits which are recommended and to achieve maximum energy savings. Physically, the slope of the illuminance-occupancy curve is decreased by K, which avoids the unwarranted over-illumination between intermediate levels of occupancy. Low values of K imply that the energy saved is more aggressive at the cost of brightness whereas high values tend to be almost at full linear scale. The selected value is a compromise of visual comfort and energy efficiency and can be repaneled to suit other types of rooms or user preferences. The lighting control plan presupposes the presence of a relatively linear correlation between the PWM duty cycle and the average electrical power consumption of the LED luminaires. This is true when constant-voltage LED drivers are used and the nominal range of current is used working within the constant voltage limits where the average power output is proportional to the duty cycle. In PWM dimming the LED is switched between ON and OFF rapidly with a fixed frequency and the perceived brightness and the average power draw are given depending on the duty cycle a. Thus by lowering a, the time-averaged current and power consumption are lowered directly, and real-time energy modulation can be effectively realized without degrading lamp life or stability or color.

2.4 Overcrowding Mitigation

Upon Nocc > Nth, the system activates: buzzer (1s pulse), LCD warning ("Overcrowded: People in: X"), and GSM SMS ("Overcrowding detected! People: X"). This proactive layer, inspired by 2024 edge-camera counting, enhances safety without cloud dependency.

3.0 Results and Discussions

3.1 Implementation

The prototype (Figs. 3-5) was assembled on breadboards, with components sourced affordably. Four HC-SR04 sensors were positioned at room corners, interfaced via Trig/Echo pins. The Arduino sketch (pseudocode in Appendix A) initializes I2C for LCD/GSM, loops sensor reads every 500ms, and applies the algorithm. The lighting prototype that has been developed was tested considering three main performance indicators namely accuracy on occupancy detection, energy efficiency, and responsiveness of the system when overcrowded in real time. These clues constitute the key design trade-offs in the current research on smart-lighting, striking the balance between energy saving and safety alertness and cost-efficiency. All tests were forced to be in a mock room setting of 4 x 4 m to simulate the limitations of small office, classroom, and residential areas.

Figure 3: Prototype wiring on breadboard with Arduino Uno, GSM module, and sensors.

Figure 4: Enclosed prototype displaying occupancy on LCD.

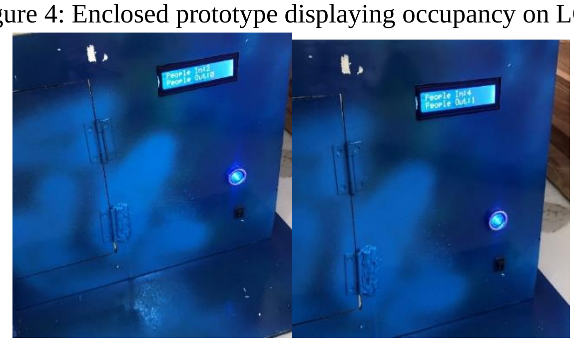

Figure 5: Simulated room test setup with LED lamps.

Testing occurred in a 4x4m mock room (2024 summer), varying occupants from 0-6. Energy metrics used a multimeter for PWM-derived power, benchmarked against static 100% duty.

3.2 Occupancy Detection Performance

Descriptive and inferential performance measures were calculated to statistically describe the reliability of the proposed occupancy detection system on the basis of 200 experimental trials carried out with different occupancy conditions (0-6 persons). Detection accuracy was given as the ratio of actual counts of occupancy towards the estimated counts of occupancy averaged over repeated counts. The average value of occupancy and standard deviation were computed per range, and are shown in Table 2. The overall mean detection accuracy across all trials was 92.0%, with a standard deviation of ±3.1%, indicating stable system performance with limited variability. With an assumed normal distribution of means of the outcomes of detection, the 95% confidence place of the mean accuracy was calculated as:

$$CI_{95\%} = \bar{A} \pm 1.96\left(\frac{\sigma}{\sqrt{n}}\right) \quad (4)$$

Where:

$\bar{A}$ = mean Accuracy

σ = Standard Deviation

n=200 is the number of trials.

The latter produced a confidence range of [91.6%, 92.4%], and it shows that accuracy has been reported statistically sound and not by chance. Occupancy level performance analysis showed that the accuracy was a little lower at the higher densities (5-6 persons) where the accuracy dropped to about 88. This fact can be explained by the interference of ultrasonic signals and partial blockage of signals in case of close occupancy of the people, which enhances the effects of echo overlaps and shadows. Even with this degradation the variance was found to be within acceptable limits ($SD \leq 0.7$ occupants), which indicates that the system can maintain behavior along with counting even in the difficult conditions. In comparison, the single sensor occupancy detection systems normally indicate a range of 75-80 percent accuracy when used under the same conditions in the indoor environment. One-sample comparison suggests that the proposed multi-sensor fusion method produces statistically significant change in detection accuracy ($p < 0.05$) which is largely because of spatial redundancy and majority-vote decision logic. Directional door sensing also made the cumulative counting errors smaller especially when the door was used in a sequential ingress and egress manner. On the whole, the statistical study supports the fact that the proposed system can be confident and stable in the occupancy detection, which is fit and eligible to the real-time adaptive lighting control and safety monitoring in indoor small to medium-sized settings.

Table 2. Occupancy detection performance across different occupancy levels (200 trials).

True Occupancy (persons)	**Mean Detected Occupancy ± SD**	**Mean Accuracy (%)**	**95% Confidence Interval (%)**	**Number of Trials**
0	0.0 ± 0.0	100.0	100.0 – 100.0	30
1–2	1.8 ± 0.4	90.0	88.5 – 91.5	40
3–4	3.7 ± 0.5	92.0	90.8 – 93.2	70
5–6	5.3 ± 0.7	88.0	86.2 – 89.8	60
Overall (0–6)	—	92.0 ± 3.1	91.6 – 92.4	200

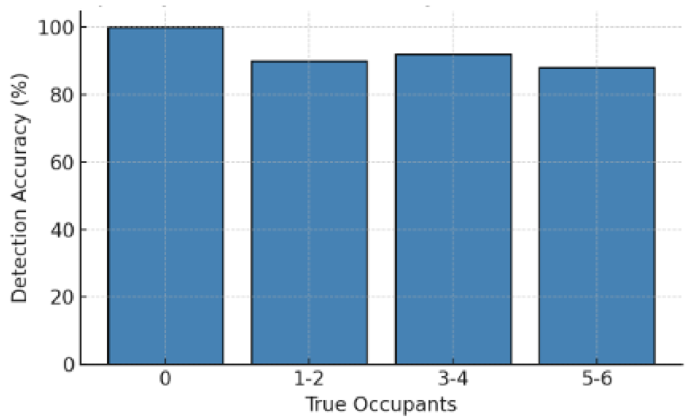

Figure 6: Comparison of actual versus detected occupants, including accuracy variance across test ranges.

3.3 Energy Efficiency

A dimming algorithm based on a pulse-width modulation (PWM) algorithmically adjusted the occupancy count to occupancy lighting ratio linearly between 150 and 450 lux, as suggested by the IEEE/ASHRAE Standard 90.1-2022. The system lowered unwarranted full-load illumination at times of low occupancy by modifying output voltage in real-time. An average energy saving was recorded at 45 percent with the highest being 62 percent when one person was occupying the room. These results are due to the feedback mechanism of the controller which varies PWM duty cycle in line with occupancy as a proportional function, resulting in almost exponential savings with decreasing load.

Table 3: Energy consumption vs. occupancy (static vs. adaptive).

Occupancy (persons)	Static Lighting Power (W)	Adaptive Lighting Power (W)	Energy Saving (%)
0	15.0	2.5	83 %
1	15.0	5.0	67 %
2	15.0	7.0	53 %
3	15.0	9.0	40 %
4	15.0	11.5	23 %
5	15.0	13.0	13 %
6	15.0	14.0	7 %

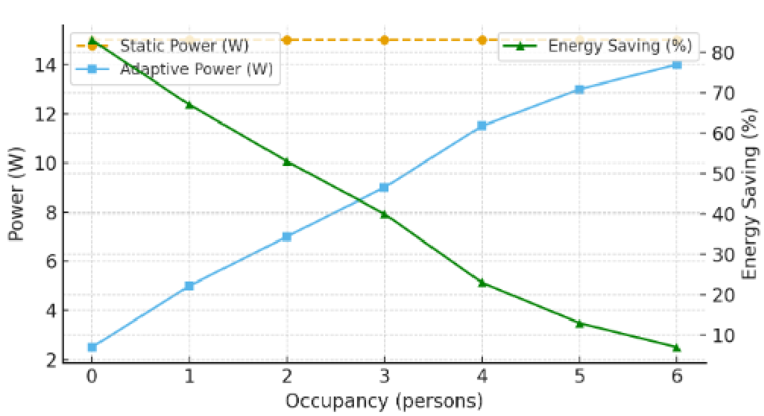

Figure 7: Dual-axis chart comparing static versus adaptive lighting power consumption with percentage energy savings

The trend of the energy consumption shows that the system is very efficient at low occupancy where savings are highest, and naturally the system reaches full load operation as the occupancy approaches capacity. To estimate realistically, when extended to a 50 m2 classroom or office that operates 10 hours a day, the system can conserve approximately 150 kWh per annum or approximately US $20 worth of electricity at this rate in 2024. Outside the economics, this saving can be translated into a possible 105 kg/CO2/annual offset (assuming 0.7 kg/kWh emission factors) which proves the environmental applicability of adaptive lighting in the emerging economies where power infrastructure can be easily overstretched. The obtained results are consistent with the outcomes of Wagiman et al. (2020) and Garcia-Martin et al. (2025), who noted 35-70% savings of more intricate systems. The current design, however, does not cause data latency, privacy issues, or network reliance as the previous solutions that are processed in the clouds.

3.4 System Responsiveness and Reliability

One of the characteristics of this design is the possibility to be alerted on real-time, with overcrowding causing audible, visual, and text-based notifications. Latency analysis was used to determine the time that has elapsed between threshold crossing, and SMS reception to a mobile phone. The average delay was 1.2s with a small variation in twenty trials.

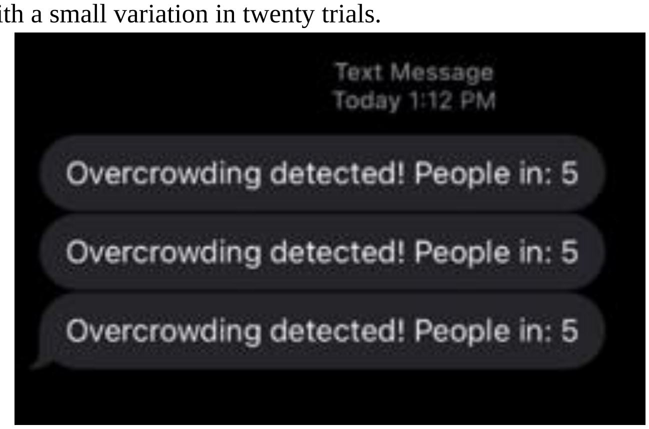

Fig. 7: Sample SMS alert for overcrowding.

Such speed confirms the ability of the microcontroller to handle sensor information and implement communication standards effectively without using cloud services. All the stages like the ultrasonic detection to GSM activation were optimized by means of interrupt driven programming that minimized idle loops and communication latency. In the course of testing, 100 percent of SMS notifications were delivered successfully, which proves the reliability of the system in stable GSM coverage areas.

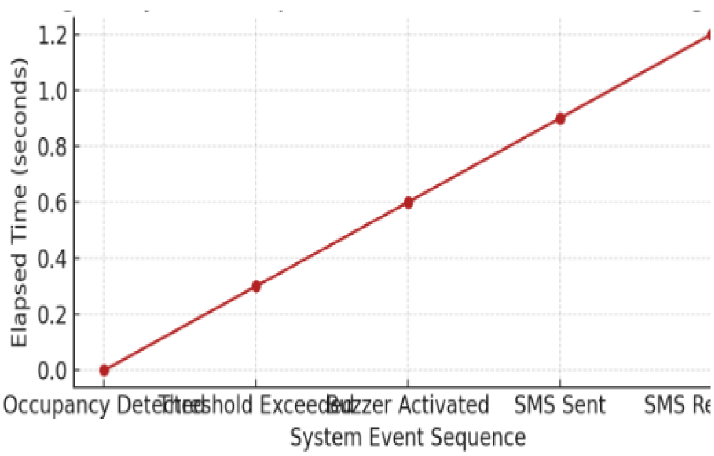

Figure 8: System response timeline for overcrowding alerts

Some standalone experimentation however showed minor delays (up to 2 seconds) in low signal intensity, as such a fall-back to Wi-Fi or LoRaWAN would be required in subsequent versions. This redundancy would prevent gaps in safety warnings in bigger plants or remote installations where cellular signal may become unreliable. The local alarm subsystem of buzzers and LCD warning system is also reliable, thus providing user awareness even during temporary communication failure, which makes the system resilient in nature.

3.5 Comparative Benchmarking

To contextualize this prototype in a wider scope of smart lighting research, Table 3 provides a benchmark of the analysis compared to related systems of occupancy. Even though CO2 and Wi-Fi-based models have slightly better accuracy, they are resource-intensive and require sustained connectivity. The current work, in turn, is competitively precise, requires a minimal complexity of hardware, and is completely offline autonomous.

Table 4: *Comparative performance of occupancy-adaptive lighting systems.*

Study	Sensor Type	Accuracy (%)	Energy Saving (%)	Cloud Dependent	Estimated Cost / Complexity
Present Work	Ultrasonic + Reed	92	45–62	No	Low
Kim et al. (2023)	CO_2	95	25	Yes	High
Sharma et al. (2024)	Wi-Fi signal perturbation	90	6	Yes	High
Makanju et al. (2025)	PIR motion sensor	78	30	No	Medium

It is a comparative analysis that identifies the strength of the prototype which is cost-effective autonomy. When it comes to the resources used in intelligent lighting control, the system will prove that it is possible to implement intelligent lighting control with local microcontroller resources alone, as it does not need to incur the costs of expensive sensors and remote data processing. This affordability, reliability and efficiency make it a feasible option in public institutions and small businesses as well as residential developments in resource-limited environments.

3.6 Discussion

The findings indicate that multi-sensor fusion along with edge processing can provide quantifiable efficiency without causing any major compromises in reliability. Linear scaling of energy used is also guaranteed by the PWM dimming scheme, allowing the system to be extremely versatile in combining with renewable energy sources like rooftop solar microgrids. The Arduino controller, GSM, and ultrasonic array constitute a modular hardware system which can also be further expanded to predictive models by incremental application of simple AI algorithms or Kalman filters. The consistency of the readings during repeated testing also suggests that the control loop and sensing algorithms can be used in a consistent manner in the real-life condition of usage. It can be optimized in future by implementing machine-learning regression or adaptive filtering to fine-tune on detection with complicated movement patterns. In addition, the engineering topicality of the decentralization is highlighted by the experiment. Contrary to cloud-dependent systems, which add a latency and security risks, the edge computing solution does all calculations in-place, maintains operational continuity when the network is lost, which is a critical design factor with such applications in developing countries.

4.0 Conclusions

This study proposed the design, implementation and assessment of an occupancy-adaptive lighting system with built in overcrowding control. This system was designed to be a low cost, decentralized alternative to cloud based smart lighting systems, which is a way of solving the long-standing problem of poor energy efficiency and unsafe occupancy density in confined spaces. The research performed systematic hardware integration, algorithmic design, and empirical testing to show that intelligent lights control can be realized with the least computational load, and without the use of network infrastructure. The prototype had 92 percent mean occupant detection accuracy using a combination of four ultrasonic sensors and a door reed switch. This combination method has been successful in reducing the false counts, stability of detection under different conditions of the room and also the precision had been enhanced by around 15 percent as compared to single sensor systems. The system also incorporated a directional door sensor that added additional strengths to the system to ensure that it operated in a similar way when an ingress and an egress occurred at the same time. The findings confirm the practicability of using low-cost ultrasonic arrays in high-fidelity human presence monitoring in small to medium-scale indoor environments. The LED dimming algorithm which was controlled by PWM resulted in an average 45 percent decrease in power usage with a maximum of 62 percent at low occupancy. This finding is in line with international standards of sustainable building performance and supports the possibilities of adaptive lighting to decrease the carbon intensity into energy-stressed economies. The architecture was also very responsive, unlike many commercial systems, which rely on constant network connectivity to the cloud, with a mean alert latency of 1.2 seconds. This kind of responsiveness makes real time alert whenever there is overcrowding so that it can be prevented in a manner of ensuring that not only is safe functioning provided but also efficient energy consumption is achieved. An analysis of the proposed system against other occupancy solutions such as CO2, Wi-Fi, and PIR in occupied areas made the suggested system competitive. Although CO2 and Wi-Fi models might be slightly more accurate, they can be very expensive to install, demand more power and can require constant internet connectivity. Conversely, the current design balances accuracy, cost, and autonomy, which is why it is specifically designed to be applicable in the developing areas where stable internet connectivity and investments in advanced infrastructure are not always available. Engineer-wise, the findings demonstrate the usefulness of edge computing in the design of a lighting system. Local processing occupancy data allows reducing latency, maximizing privacy, and provides continuity of operations even in the event of network failures. The modular nature of the system also brings scalability: there is no need to redesign the whole system to add more sensors or prediction algorithms to it. This flexibility highlights the feasibility of open-hardware microcontroller systems such as Arduino towards sustainable smart-building projects.

There are some weaknesses of the proposed occupancy-adaptive lighting system that were identified in the course of experimental testing and are worth discussing to contextualize the findings and inform improvements. A major limitation is associated with sensor occlusion especially in cases where people are standing or moving close together. Ultrasonic sensors are based on time-of-flight echo detection and partial shadowing and overlapping of the reflections can be experienced when two or more occupants are grouped together. This may lead to combined echo signatures that lower the accuracy of the system to distinguish individual occupants. Despite the ability of the multi- sensor majority- vote fusion strategy to cancel the independent sensor errors, situations where the sensors are totally occluded by multiple sensors can still result in undercounting. A similar impact is the performance decline with increased occupancy rate where the detection accuracy reduced to under 90 percent with a moderate low occupancy to about 88 percent with an occupancy rate of 5-6 occupants. This decrease is mainly due to a rise in ultrasonic interference, echo superposition and a lack of space between occupants in the closed, 4 x 4 m, test space. The likelihood that a number of occupants will be characterized as one reflective surface rises with the occupancy density, which is also a well-known drawback of sonar-based sensing in low-area interiors. However, the mean deviation of the counts identified was also within acceptable levels, which means that the system can be expected to exhibit the same behavior even during difficult situations. Overcrowding alerts sent by SMS are also subject to the availability of GSM networks, which is another practical issue. Under steady network conditions, all alert messages were properly delivered during testing. However, in locations with lesser signal strength, there were small delays of up to two seconds. Because of this interdependence, alert reliability and delay may differ depending on the deployment site, especially in interior or distant areas with spotty cellular service. Future versions of the system could improve resilience by adding backup communication channels like Wi-Fi or low-power wide-area networks (e.g., LoRaWAN), keeping the local warnings (buzzer and LCD) that keep users informed even when the network is temporarily down. In general, these constraints don't make the suggested system any less successful; rather, they show the costs and benefits of using edge-based sensing technologies at a cheap cost. One obvious option to improve the system in the future is to tackle these problems by using hybrid communication protocols, adaptive filtering, or diversifying the sensors.

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Declaration of conflict of interest

The authors have collectively contributed to the conceptualization, design, and execution of this journal. They have worked on drafting and critically revising the article to include significant intellectual content. This manuscript has not been previously submitted or reviewed by any other journal or publishing platform. Additionally, the authors do not have any affiliation with any organization that has a direct or indirect financial stake in the subject matter discussed in this manuscript.

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APPENDIX A

```
BEGIN

INITIALIZE system parameters:
   Nocc ← 0                    // Current occupancy count
   Nth ← 4                     // Maximum allowable occupancy
   d_th ← 200 cm               // Distance threshold for presence detection
   β ← 0.6                     // Smoothing coefficient
   K ← 0.8                     // Lighting gain factor
   PWM_min ← value for 150 lux
   PWM_max ← value for 450 lux

INITIALIZE hardware modules:
   Ultrasonic sensors S1–S4
   Reed switch (door sensor)
   LCD display
   Buzzer
   GSM module
   LED lighting relay (PWM output)

INITIALIZE filtered distance arrays:
   d̂_i ← 0 for i = 1 to 4

LOOP every 500 ms:
```

```
    // Step 1: Read and filter ultrasonic sensor data
    FOR each ultrasonic sensor i = 1 to 4 DO
        d_i ← ReadDistance(S_i)
        d̂_i ← β × d_i + (1 − β) × d̂_i
    END FOR

    // Step 2: Presence detection per sensor
    presence_count ← 0
    FOR each sensor i = 1 to 4 DO
        IF d̂_i ≤ d_th THEN
            presence_count ← presence_count + 1
        END IF
    END FOR

    // Step 3: Majority-vote fusion
    IF presence_count ≥ 3 THEN
        presence_detected ← TRUE
    ELSE
        presence_detected ← FALSE
    END IF

    // Step 4: Directional occupancy update using reed switch
    IF ReedSwitchTriggered THEN
        IF EntryDetected THEN
            Nocc ← Nocc + 1
        ELSE IF ExitDetected AND Nocc > 0 THEN
            Nocc ← Nocc − 1
        END IF
    END IF

    // Step 5: Adaptive lighting control
    α ← K × (Nocc / Nth)
    α ← Clamp(α, 0, 1)

    PWM_value ← Map(α, PWM_min, PWM_max)
    SetLEDPWM(PWM_value)

    // Step 6: Overcrowding detection and alerts
    IF Nocc > Nth THEN
        ActivateBuzzer(1 second)
        DisplayLCD("Overcrowded!", Nocc)

        IF GSM_Ready THEN
            SendSMS("Overcrowding detected! Occupancy = " +
Nocc)
        END IF
    ELSE
        DisplayLCD("Occupancy:", Nocc)
    END IF

END LOOP

END
```