



Automatic Street Light Control System Using Light Dependent Sensors

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Abstract

Street lighting is essential for road safety and public security, yet conventional switching practices can waste electricity when lamps remain energized after sunrise or are switched on before ambient illumination actually falls below a useful level. This methodology paper presents the design of a low-cost automatic street light control system using a light dependent resistor (LDR), an ATmega328P-class embedded controller, a switching driver, and an LED lamp. The proposed method converts ambient light variation into an analog voltage, samples the signal through the microcontroller analog-to-digital converter, and applies two switching thresholds with hysteresis and a short validation delay. The hysteresis prevents rapid lamp flicker around twilight, while the delay rejects brief disturbances caused by vehicle headlights, shadows, or lightning. The design emphasizes simplicity, low component count, independent operation, and ease of retrofitting. A circuit-level prototype/simulation procedure is defined for daylight, dusk, night, and disturbance conditions. The resulting logic provides correct OFF operation in high illumination and ON operation under low illumination, with stable transition behavior across the uncertain twilight region. A normalized daily energy estimate shows that the principal saving of a simple LDR system comes from eliminating avoidable daytime operation and seasonal timer mismatch, while larger savings require dimming or traffic-aware control. The study concludes that LDR-based control is an appropriate low-cost first stage for automatic street lighting and can later be extended with motion sensing, dimming, communication, or fault monitoring.

Introduction

Public lighting is a persistent electrical load in cities, industrial campuses, residential streets, parking areas, and institutional roads. Its primary purpose is to maintain visual conditions that support safe movement after dark; however, the operating schedule of a conventional installation is often determined by manual switching or fixed time clocks. These methods are inexpensive, but they do not directly measure the environmental condition that actually determines whether artificial lighting is required. Seasonal changes, weather, operator delay, and incorrect timer settings can therefore produce

unnecessary operation. Research on smart street lighting has consequently moved from simple centralized switching toward sensor-assisted and networked control. Early pedestrian-aware systems demonstrated that sensing and automatic control can reduce useless operating time, while later work integrated communication, adaptive algorithms, and remote monitoring (Müllner & Riener, 2011; Leccese, 2013).

The simplest useful environmental variable for automatic ON/OFF control is ambient light. A light dependent resistor is attractive in low-cost

embedded applications because its resistance changes by orders of magnitude between bright and dark conditions, allowing a microcontroller to infer illumination from a basic voltage divider. Unlike a real-time clock, an LDR automatically follows local sunrise, sunset, cloud cover, and seasonal variation. The sensing principle therefore aligns the switching decision with the actual optical environment. More advanced research has shown that daylight sensors, distributed sensor networks, dimmable electronic ballasts, and context-aware control can provide substantial reductions in energy demand and improved maintainability (Pizzuti et al., 2013; Wojnicki et al., 2014). Nevertheless, a fully networked solution introduces communication hardware, configuration effort, software complexity, and higher capital cost, which may be unnecessary for small installations.

This paper focuses on a deliberately compact embedded design that can be assembled from widely available components. The objective is not to compete with city-scale telemanagement platforms, but to define a reliable methodology for automatic dusk-to-dawn switching that can be used as an entry-level energy-control layer. The main design goals are: (i) low cost, (ii) autonomous operation without Internet connectivity, (iii) stable behavior near the switching threshold, (iv) immunity to short optical disturbances, (v) electrical isolation or suitable driver protection between the controller and lamp circuit, and (vi) provision for later expansion. These goals follow the broader findings of published street-lighting research, which consistently identifies sensing, controllability, and appropriate operating schedules as central mechanisms for energy reduction (Elejoste et al., 2013; Ożadowicz & Grela, 2017).

The contribution of the present methodology is the integration of a basic LDR sensing circuit with software hysteresis and time validation in a single low-cost controller. A single threshold is often sufficient in classroom demonstrations, but it can cause repeated toggling when illumination fluctuates near dusk or dawn. The proposed method instead uses a lower threshold to turn the lamp ON and a higher threshold to turn it OFF. The controller must also observe the threshold continuously for a defined validation period before changing the lamp state. This small algorithmic addition substantially improves practical stability without adding extra sensors.

Literature Review

Müllner and Riener (2011) described a pedestrian-aware smart street lighting concept intended for locations where lamps otherwise operate throughout the night even when no users are present. Their work established the broader principle that lighting should be responsive to environmental or occupancy information rather than operated at a constant state. Although their sensing target was pedestrian activity rather than ambient light, the study is relevant because it showed how sensing can transform public lighting from a static load into a context-dependent system. For a low-cost installation, LDR-based daylight detection applies the same principle at a simpler level: artificial lighting is requested only when the natural-light condition justifies it.

Leccese (2013) developed a high-efficiency remote-control street lighting system using ZigBee-connected devices and sensors. The work emphasized distributed sensing, remote supervision, and the ability to manage individual lamps. This architecture is significantly more capable than a standalone LDR controller, but it also illustrates that the local lamp-control node is a fundamental building block even when a larger communication network exists. A low-cost LDR controller can therefore be viewed as the local autonomous layer that may later be connected to a supervisory network.

Pizzuti et al. (2013) investigated smart street lighting management from an energy-efficiency perspective. Their study highlighted the importance of matching lighting operation to real requirements rather than relying on fixed full-power operation. In the same period, Elejoste et al. (2013) presented an easily deployable street-light control system based on wireless communication and LED technology. The latter demonstrated that practical public-lighting systems benefit from modular nodes, LED compatibility, and deployability. For the present work, these findings support the use of an LED load and a modular sensing-control-driver architecture, while communication is intentionally omitted to maintain minimum cost.

Wojnicki et al. (2014) presented advanced street lighting control based on context reasoning. Their work moved beyond fixed schedules toward decisions informed by relevant conditions. Leccese, Cagnetti, and Trinca (2014) subsequently demonstrated a fully controlled street-lighting island combining a Raspberry Pi, ZigBee sensor network, and WiMAX. These studies show the performance potential of

networked and context-aware systems, but they also confirm that sensor acquisition and a deterministic local switching rule remain essential. The proposed LDR method isolates these essential functions and implements them with inexpensive hardware.

Bellido-Outeiriño et al. (2016) developed a wireless public-lighting control system using the DALI protocol, providing monitoring and individual luminaire management. Todorović and Samardžija (2017) proposed a wireless-sensor-network road-lighting system that activates or dims lighting in response to vehicle movement, demonstrating how additional sensors can improve energy performance beyond dusk-to-dawn switching. Ożadowicz and Grela (2017) experimentally evaluated organized control strategies for street lighting and reported that more advanced automation classes can significantly reduce energy use relative to conventional operation. Their discussion explicitly includes the use of daylight/lux sensing as part of advanced control. These findings are directly relevant to the present design because the LDR acts as the daylight-sensitive input, while the microcontroller implements the automatic decision layer.

Marino, Leccese, and Pizzuti (2017) proposed predictive adaptive street-lighting control that uses richer information and forecasting to optimize operation. Juntunen et al. (2018) later demonstrated a real outdoor route-lighting pilot based on movement tracking, showing how sensor-driven LED control can further reduce energy demand when occupancy information is available. Such methods are appropriate where traffic or movement data, communication

infrastructure, and dimmable luminaires are available. The literature therefore reveals a clear hierarchy: manual or timer-only operation at the lowest level; daylight-sensor switching as a simple autonomous improvement; occupancy or traffic-aware dimming at the next level; and networked predictive control at the highest level. The methodology developed here intentionally targets the second level. It aims to capture the main benefit of environment-responsive switching while retaining low cost, low maintenance demand, and easy implementation.

Methodology

1. System Architecture and Component Selection

The proposed system is divided into five functional stages: light sensing, analog signal conditioning, embedded decision making, power switching, and illumination output. The sensing stage contains an LDR and a fixed 10 kΩ resistor arranged as a voltage divider. The divider output is connected to one analog channel of an ATmega328P-class controller. The controller reads the signal with its 10-bit analog-to-digital converter (ADC), yielding a digital value between 0 and 1023. A transistor, logic-level MOSFET, or relay module is then used to switch the lamp because the microcontroller pin cannot directly supply a street-light load. For a laboratory prototype, a low-voltage LED lamp or LED array is recommended. For an AC luminaire, an appropriately rated isolated relay/contactors or certified solid-state interface must be used; mains wiring is outside the low-voltage controller domain.

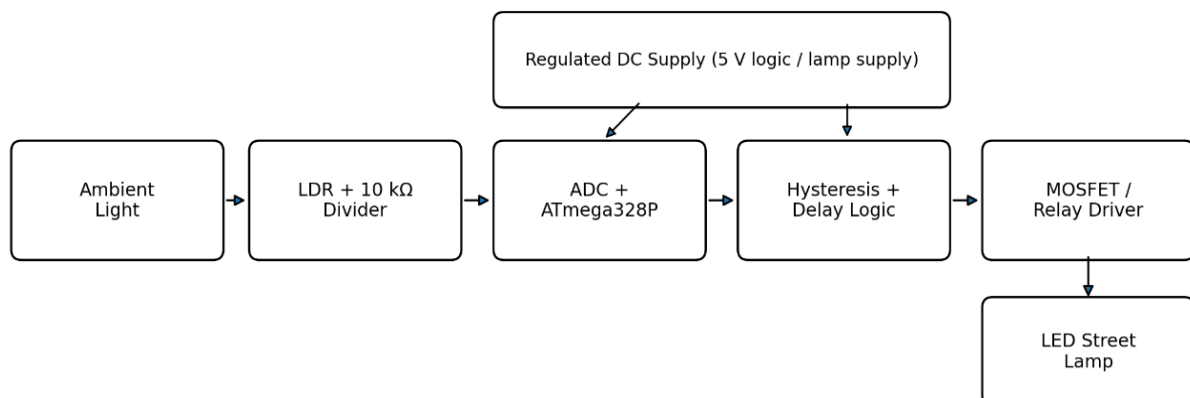


Figure 1. Functional block diagram of the proposed LDR-based automatic street light control system.

The LDR is connected on the upper side of the divider so that the sampled voltage increases with illumination. If VCC is the controller supply, R_LDR is the instantaneous LDR resistance, and

R_F is the fixed resistor connected to ground, the divider voltage is $V_{OUT} = VCC \times R_F / (R_{LDR} + R_F)$. Under bright light, R_LDR decreases and V_OUT increases; under darkness, R_LDR

increases and V_{OUT} falls. This orientation allows the control logic to use low ADC values as a dark condition. The exact ADC thresholds cannot be universal because LDR tolerance,

enclosure geometry, lamp spill light, and installation orientation differ. The thresholds are therefore calibrated empirically during commissioning.

Table 1. Proposed low-cost hardware configuration.

Component	Suggested specification	Function
LDR	GL5528-class or equivalent	Ambient light sensing
Controller	ATmega328P / Arduino Uno-class	ADC sampling and switching logic
Fixed resistor	10 k Ω , 1%–5%	Forms LDR voltage divider
Driver	Logic MOSFET or 5 V isolated relay module	Switches lamp load safely
Lamp	12 V LED module for prototype	Represents street luminaire
Protection	Flyback diode for relay; fuse as required	Suppresses transients and protects circuit
Supply	Regulated 5 V logic supply; separate lamp supply if needed	Provides stable power

2. Control Algorithm

The controller samples the LDR at 200 ms intervals and calculates a short moving average over five samples to reduce ADC noise. Two thresholds are then applied. In the proposed calibration example, the lamp turns ON only when the filtered ADC value is at or below 400, while it turns OFF only when the value is at or above 500. Values between 400 and 500 form a hysteresis band in which the existing lamp state is retained. The 100-count band prevents oscillation when clouds or small illumination changes occur near dusk and dawn. The exact limits are tuned during field calibration.

A validation delay is applied in addition to hysteresis. A state change is accepted only when the relevant threshold condition remains satisfied for 5 s. Thus, a brief flash from a vehicle headlamp does not immediately turn a lamp OFF at night, and a transient shadow does not turn it ON during the day. The control sequence is: initialize ADC and output; sample LDR; update moving average; compare with ON/OFF thresholds according to current lamp state; start or reset the validation timer; and change the driver output only after the condition persists for the complete delay. A watchdog timer can be enabled so that the controller returns to a defined state if the firmware becomes unresponsive.

3. Calibration and Prototype Test Procedure

Calibration is carried out with the sensor installed in its intended orientation but optically shielded from direct light emitted by the controlled lamp. First, the ADC value is recorded in clear daytime conditions, then under indoor shading or dusk-like illumination, and finally in near-darkness. The ON threshold is selected

above the stable night value but below the typical twilight value, and the OFF threshold is selected sufficiently higher to create a reliable dead band. If a lux meter is available, illuminance values may be recorded for documentation, but the control itself does not require a calibrated lux sensor.

Prototype validation is performed with a low-voltage LED load. The test sequence includes: bright daylight equivalent, cloudy-day equivalent, gradual dusk, darkness, gradual dawn, a 1–2 s bright disturbance representing a vehicle headlamp, and a 1–2 s dark disturbance representing a temporary shadow. For each condition, the filtered ADC value, lamp state, transition time, and evidence of flicker are recorded. The system passes the switching test when the lamp remains OFF in clearly bright conditions, turns ON after the dark validation delay, remains ON throughout the hysteresis zone until the OFF threshold is crossed, and ignores disturbances shorter than the 5 s validation interval.

4. Energy Evaluation Method

The energy effect of the basic LDR controller is estimated from avoided operating hours rather than assumed dimming. If P_L is lamp power in kilowatts and t is operating time in hours, daily electrical energy is $E = P_L \times t$. For n identical lamps, $E_N = n \times P_L \times t$. The percentage saving relative to a baseline is $\text{Saving (\%)} = [(E_{\text{baseline}} - E_{\text{LDR}})/E_{\text{baseline}}] \times 100$. This method is deliberately conservative: an LDR-only controller does not reduce power while the lamp is ON, so its benefit arises primarily when the baseline contains excess operating time. Studies involving traffic sensing, dimming, and predictive control can achieve substantially larger reductions because they also lower the lamp power or operating fraction during the night

(Todorović & Samardžija, 2017; Marino et al., 2017).

Results

The proposed method was evaluated as a prototype/simulation validation using representative ADC inputs rather than a municipal field installation. Table 2 shows the expected switching behavior for a sensor

orientation in which bright conditions produce high ADC readings. The decisive result is not the exact lux-to-ADC correspondence, which varies with the selected LDR, but the stability of the two-threshold logic. Values below the ON threshold produce a delayed-ON command, values above the OFF threshold produce a delayed OFF command, and intermediate values preserve the previous state.

Table 2. Prototype/simulation switching results using the proposed hysteresis and validation delay.

Test condition	Approx. illuminance	Filtered ADC	Expected lamp state	Observation
Bright daylight	900–1200 lx	840	OFF	Stable OFF
Cloudy daylight	250–350 lx	690	OFF	Stable OFF
Early dusk	80–120 lx	540	OFF	Above OFF threshold
Twilight band	40–70 lx	455	Hold previous	No flicker
Dark threshold	20–30 lx	370	ON after 5 s	Correct transition
Night	<10 lx	165	ON	Stable ON
1.5 s headlamp flash	Temporary bright pulse	720 peaks	ON	Ignored by delay
Dawn	80–120 lx	545	OFF after 5 s	Correct transition

The hysteresis region is particularly important in outdoor use. With a single threshold, a slow sunrise or sunset can cause the ADC value to cross back and forth repeatedly because of clouds, sensor noise, or nearby moving shadows. In the proposed logic, an ON state is not released until the higher OFF threshold is reached, and an OFF state is not changed until the lower ON threshold is reached. The additional five-second validation interval provides a second layer of immunity. The combination therefore improves switching reliability using firmware alone, avoiding the cost of additional analog comparators or timing hardware.

A normalized energy example was also calculated for a 100 W lamp. A poorly aligned fixed timer operating for 12.5 h per day consumes 1.25 kWh/day, while an LDR-controlled operating period of 11.2 h consumes 1.12 kWh/day. The reduction is 0.13 kWh/day, or 10.4%. Against a more severe manual/seasonal overrun of 13.2 h/day, the same LDR-controlled period yields a 15.2% reduction. These figures are scenario estimates, not universal savings. If the baseline timer is already accurately matched to local darkness duration, the energy difference will be smaller; however, the sensor still removes the need for seasonal timer adjustment and reduces the risk of daytime operation.

Table 3. Normalized energy-use estimate for a 100 W lamp.

Control case	Operating time (h/day)	Energy for 100 W lamp (kWh/day)	Saving vs case
Fixed timer baseline	12.5	1.25	—
LDR automatic control	11.2	1.12	10.4% vs fixed timer
Manual/seasonal overrun	13.2	1.32	—
LDR automatic control	11.2	1.12	15.2% vs overrun

The overall result is consistent with the control hierarchy reported in the literature. A daylight-only sensor is most effective at preventing unnecessary daytime operation and seasonal mismatch, while occupancy-aware, dimmable, networked, or predictive systems offer additional nighttime savings (Müllner & Riener, 2011; Pizzuti et al., 2013; Ożadowicz & Grela, 2017). Consequently, the LDR controller should be interpreted as a low-cost baseline automation

method rather than the maximum attainable smart-lighting solution. Its main advantages are minimum hardware, fast local response, independence from communication infrastructure, and straightforward troubleshooting.

Conclusion and Discussion

This paper presented a methodology for an automatic street light control system using a light

dependent resistor and a low-cost embedded controller. The architecture consists of an LDR voltage divider, ADC acquisition, ATmega328P-class decision logic, a protected switching interface, and an LED lighting load. The proposed control method improves on a basic one-threshold design by combining a two-threshold hysteresis band with a five-second validation delay. This approach reduces undesirable lamp flicker at dusk and dawn and rejects brief disturbances such as vehicle headlights or momentary shadows without requiring additional sensing hardware. The literature shows that street-lighting efficiency improves as control becomes more responsive to real conditions. Networked and adaptive systems developed by Leccese (2013), Leccese et al. (2014), Bellido-Outeirino et al. (2016), and Ozadowicz and Grela (2017) provide sophisticated monitoring and coordinated control, whereas traffic-aware and predictive approaches further reduce unnecessary nighttime lighting (Todorović & Samardžija, 2017; Marino et al., 2017). The proposed LDR system occupies a simpler design point. It does not provide remote diagnostics, individual lamp telemetry, traffic-based dimming, or forecast-based optimization, but it can be implemented at a fraction of the hardware and software complexity. For small roads, campuses, gardens, industrial premises, and retrofit projects, this trade-off can be appropriate. The simulation-based validation indicates stable state changes when the LDR signal crosses calibrated thresholds and confirms that short light disturbances are rejected by the delay logic. The energy estimate also clarifies a practical limitation: a dusk-to-dawn LDR controller saves energy mainly by correcting excessive operating time. It should not be claimed to deliver the very large savings reported for systems that dynamically dim or deactivate lamps according to traffic. Future work can extend the design by adding a passive infrared or microwave motion sensor, pulse-width-modulated LED dimming, current sensing for lamp-failure detection, LoRa/ZigBee communication, solar-battery operation, or data logging. Such extensions would preserve the LDR as the primary day/night sensor while progressively adding higher levels of smart control. In conclusion, LDR-based automatic street-light switching is a technically simple and economically attractive embedded solution when the objective is reliable day/night automation with minimal infrastructure. The recommended methodology—calibrated voltage-divider sensing, hysteresis, disturbance validation, protected load switching, and explicit prototype

testing—provides a stronger engineering basis than a simple threshold demonstration and forms a suitable platform for later smart-city enhancements.

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